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THE REFITTING OF THE "QUEEN OF BERMUDA".

The turbo-electric propulsion machinery and auxiliary electrical gear, originally built by the G.E.C., have been completely overhauled. The scheme of lighting is entirely new. The illustration is of the first-class lounge in which cold cathode indirect cornice lighting is used in the wings and round the ceiling.

The "Queen of Bermuda"

A NOTE ON THE REFITTING OF A LUXURY LINER AFTER SIX YEARS' WAR SERVICE.

AFTER six years' war service both as an armed merchant cruiser and as a troopship, the quadruple screw, turbo-electric liner, "Queen of Bermuda", resumed her sailings between New York and Bermuda on February 12th, 1949. To some extent she is a new ship, her electrical equipment having been completely overhauled by The General Electric Co. Ltd., who originally built and installed the turbo-electric propulsion machinery and auxiliary electrical gear. It is the largest refit ever undertaken by one electrical firm.

Her record of reliability has been truly outstanding.

The owners, Furness, Withy & Co., Ltd., state that she has not missed a single sailing due to overhauling or any failure of the machinery. Over a period of eleven years she covered 40,000 miles, and during the whole of that time the turbines and motors were opened up only for survey purposes by the B.O.T. and Lloyds. With the advent of the war there was naturally some anxiety as to how she would stand up to the effects of gun firing or near misses. Events proved that neither of these had the least effect on the machinery, although other parts suffered slightly. The owners add that, after having seen turbine reduction gearing stripped as a result of near misses, they are wholeheartedly in favour of turbo-electric drive. Further, it is of interest to record that the upkeep of all the electrical equipment for a period of nine years, from February, 1933 to March, 1942, cost only £576.

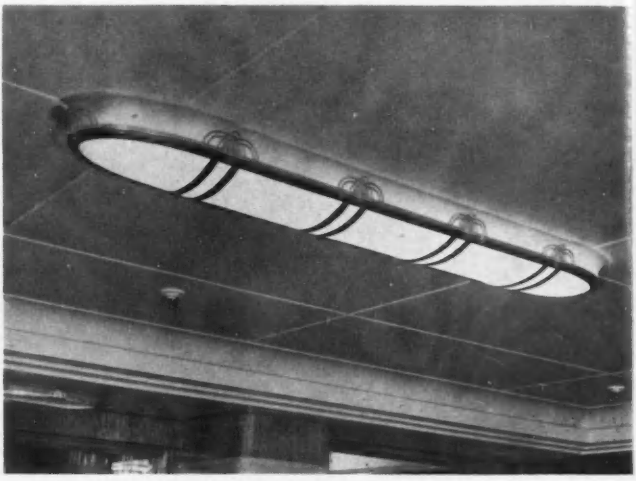
The "Queen of Bermuda" is an all-electric ship; in addition to the propulsion machinery and auxiliary electrical equipment, electricity is used for lighting, ventilation, cooking and refrigeration, passenger and goods lifts, the handling of cargo, laundry machinery, gymnasium apparatus, printing presses, fire alarms, loudspeakers

The library affords an excellent example of the harmonious blending of cold cathode indirect cornice lighting with the tungsten light from the central ormolu ceiling fitting.

and the raising of the lifeboats.

The scheme of lighting is entirely new throughout the vessel. Cold cathode fluorescent tubes are used extensively and constitute the largest lighting installation of this type afloat, employing almost three-quarters of a mile of tubing. In most cases indirect cornice lighting is adopted, continuity being obtained by turning back the ends of electrodes so that the tubes butt against one another.

The first-class dining saloon is lit by gold and warm white tubes set in the cornices with further tubing in a glazed cornice round the central well and in the laylight that crowns the vaulted ceiling. Cold cathode tubes are also used in the elongated ceiling fittings at each end of the saloon. Tungsten lamps in tinted glazed fittings are skilfully introduced to blend with the fluorescent lighting. The effect of the combination is light of a most pleasing quality, with excellent colour rendering, which is kind to the complexion. The dining saloon foyer is illuminated by a number of handsome laylights containing tungsten lamps ; the metalwork of the laylights is satin silver and the glass is of medium pink.



A decorative ceiling fitting in the dining saloon with gold and white cold cathode tubes.

An effective combination of cold cathode indirect lighting and tungsten lamps in a first-class writing-room.

Indirect cornice lighting with warm white tubes is also used in the first-class lounge. Here again tungsten lamps are judiciously introduced in dispersive reflectors in the laylight in the centre of the ceiling. A striking feature is the four ornamental silver-plated standards, one at each side of the stage and at both sides of the inglenook.

For the dance hall there are three peach-tinted circular fittings in the ceiling, the outer areas of the hall being indirectly lit from warm white tubes in the cornices supplemented by a continuous run of tubing in a glazed trough. The entire illumination of the hall, which includes several tungsten fittings, is under the control of a colour changing and dimming device.

By contrast, the blending of cold cathode and tungsten light in the library and writing-rooms is carefully planned to give a peaceful even light affording ample illumination.

In all respects the ship may justly be considered a worthy example of British enterprise, quality and craftsmanship.

Fig. 1.—Rosario South from the Parana River.

Grain Elevators in Argentina

By H. R. HANBIDGE,

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INTRODUCTION.

FOR a number of years much discussion has taken place in the Argentine Republic regarding ways and means of giving the country a better and more efficient method of handling, storing and shipping its very considerable grain crops, but it was not until the early 'thirties that the necessary legislation was passed by the Argentine Congress, eventually leading to concrete proposals.

Studies were made by Argentine and foreign engineers and a plan and specification of materials were drawn up for the erection of a large number of receiving and storage silos in the Argentine country districts, which were to receive and store grain for the farmer until such time as he wished to sell his products. Large terminal elevators were also to be constructed along the principal rivers and at the main ports on the sea coast in order to receive, store, clean, classify and ship grain all over the world.

In the year 1936 public tenders were invited to cover some of the most important terminal elevators and, finally, contracts were placed for four new elevators and for the extension of an existing fifth. Henry Simon Ltd. was awarded the contracts for three new elevators and for the extension of the " Ingeniero White " elevator, for which that firm had been main contractors some years before, orders for the buildings being placed separately. The G.E.C. acted as sub-contractors for the electrical machinery and equipment for these elevators and the Anglo-Argentine General Electric Co. Ltd. was responsible for the erection of the whole of the electrical plant.

MAIN CHARACTERISTICS.

The four grain elevators constructed were as shown in the table on page 67.

The Rosario South elevator, seen in fig. 1, is situated on the right bank of the Parana river in the port zone of the city of Rosario about 200 miles north-east of Buenos Aires and some 350 miles from the open sea. This port in pre-war days ranked second to Montreal as a grain exporting centre.

The second elevator is also situated on the Parana river, between Rosario and Buenos Aires, in the town of Villa Constitucion (pop. 14,000). Fig. 2 gives a general view of this elevator, excluding the shipping gallery.

The third elevator was erected on the South Atlantic coast at the mouth of the Quequen river, some 350 miles south of Buenos Aires and about 100 miles south of the famous seaside resort, Mar del Plata. Fig. 3 shows this elevator nearing completion.

At Ingeniero White in the district of Bahia Blanca on the South Atlantic seaboard of the Province of Buenos Aires the existing elevator, which was built in the late 'twenties, was

Fig. 2.—General view of the Villa Constitucion in course of construction. The sack shed is seen in the foreground.

extended and an annex building constructed to receive grain brought in by road transport. The construction of this extension is shown in fig. 4.

GENERAL DESCRIPTION OF A GRAIN ELEVATOR.

These terminal grain elevators are very large buildings designed to receive, store, clean classify and ship grain, and consist of the following six sections.

(1) A reception section for the intake of grain transported by rail from the growing districts.
(2) A reception section for the intake of grain from lorries.
(3) A handling section, where the different grains are weighed, inspected, tested for moisture and specific gravity, sorted and cleaned. From this section the grains are distributed to the storage silos or shipped.
(4) A storage section where the classified

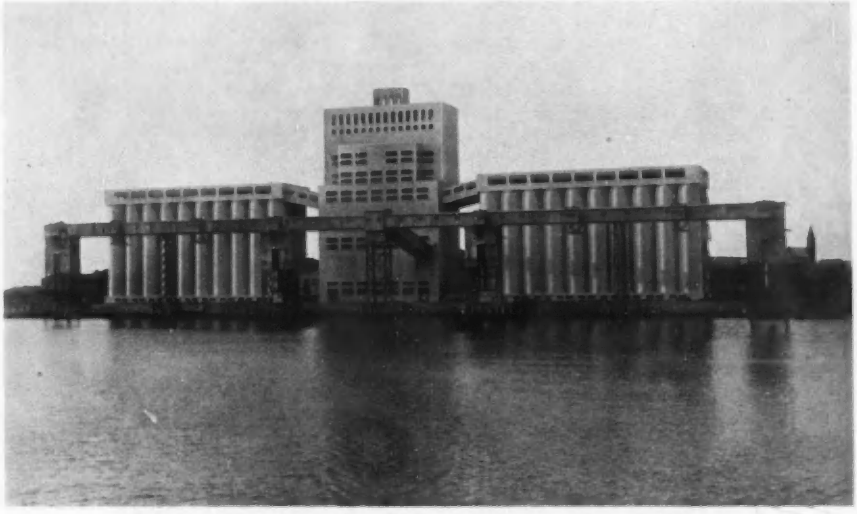


Fig. 3.—General view of the Quequen elevator nearing completion.

grain is stored in the familiar round-shaped silos to await shipment.

(5) A drying section, where as much moisture as possible is removed from the grain to prevent fermentation.

(6) A shipping section, where the grain is automatically loaded by conveyor into ships for transport to all parts of the world.

working house and the shipping gantry in front; Quequen is a similar layout relative to the waterway but the working house is in the centre of two blocks of silos; Villa Constitucion resembles Rosario South externally, but the working house, silos and shipping gantry are all in a straight line at right angles to the river bank.

	Rosario South	Villa Constitucion	Quequen	Ingeniero White Extension
Storage capacity (tons)	65,000	49,000	41,000	—
Working house bins (tons)	8,600	3,700	6,100	—
Total capacity (tons)	73,600	52,700	47,100	61,000
Daily Receiving Capacity				
By rail (tons)	4,200	3,700	2,850	—
By road (tons)	2,350	1,580	2,250	—
Daily shipping capacity (tons)	8,750	5,500	6,500	—

Each elevator is designed to handle and treat the particular variety of grain grown in the district in which it is situated; for example, the Rosario South and Villa Constitucion elevators are mainly intended to handle maize and the harder varieties of wheat grown in the hotter north-central zones; Quequen and Ingeniero White are devoted to the softer types of wheat, oats, barley, etc.

In design, the three new elevators are quite different, the layout depending on the site conditions relative to the adjacent roads and waterways. The Rosario South elevator is built parallel to the river, with its block of silos at one side of the

BRIEF DESCRIPTION OF THE DIFFERENT SECTIONS OF THE GRAIN ELEVATORS CONSTRUCTED.

(1) The Rail Receiving Section.

This section comprises a large shed of reinforced concrete, open at the ends and equipped with dust extractors which are located in the roof. The shed is crossed by a number of rail tracks usually four or more in number depending upon the reception capacity for which the elevator is designed. Sidings are provided at each end of the shed to shunt wagons of 40/45 tons capacity. The loaded wagons are rapidly discharged by means of mechanical power shovels, operated by 5 h.p. motors, the grain falling

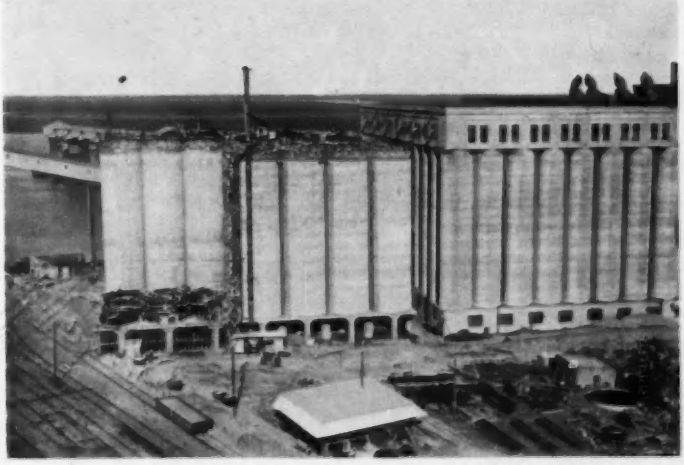


Fig. 4.—Extension of the storage bins at the Ingeniero White elevator.

Fig. 5.—Maize being discharged from lorries at Villa Constitucion.

through grids into the hoppers immediately below the wagons. These hoppers are fitted with valves and feed the grain on to the conveyors which are situated below the distribution hoppers and carry the grain into the required section of the elevator. The receiving office is located at the side of this shed. Here a check is made of the incoming wagons, and samples taken of each bag of grain received. In the case of grain unloaded in bulk, the samples are taken as the grain falls into the hoppers. The wagons are manipulated into position by long wire ropes operated by capstans driven by 23 h.p. motors.

(2) The Road Receiving Section.

This section is similar to that for rail reception, but situated on the opposite side of the elevator. Loaded lorries are weighed at the weighbridge before they pass into the shed and discharge their contents through a trap-door in the bottom of the truck, on to the grids and into the hoppers. Distribution of the grain then follows the same routine as in the case of rail intake. There is an office in the vicinity to control movement and to attend to sampling. Fig. 5 shows maize being discharged from a lorry with a trailer at Villa Constitucion.

The activity in this section when grain is being brought in after the harvest season is remarkable. A queue of lorries, each one with its trailer, stretching as far as two miles may be seen on the road which approaches the elevator. Even though eight lorries are discharged at the same time in four rows of two, the queue does not shorten until evening time as an endless stream of trucks continues to arrive from the storage points in the interior. It is quite common to see grain being unloaded direct from lorries into ships and work proceeding throughout the night.

(3) The Working House.

The working house is that part of the building which stands high above the wings of the storage section, and has a number of different floors :

(*a*) The basement, in which are situated the intake conveyors, elevator boots, the driving end of the intake and under-bin conveyors, the worm conveyors, etc.

(*b*) The elevator head floor, to which the grain is elevated before being distributed by gravity to the different sections of the elevator. On this floor will be found the

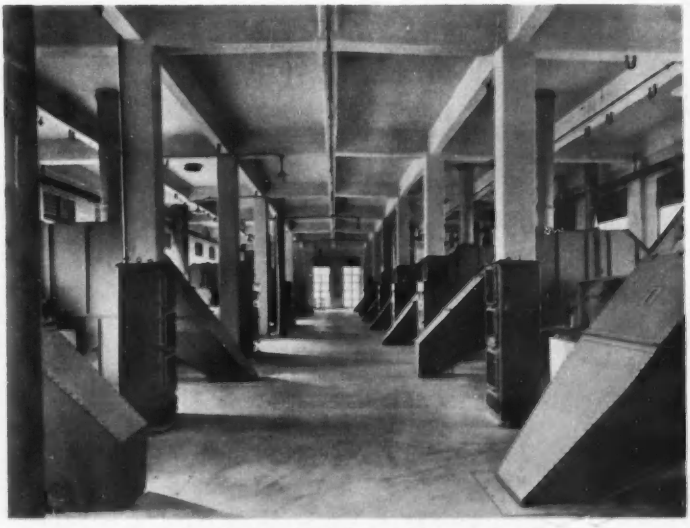


Fig. 6.—Elevator head floor at Rosario South.

largest motors installed and it is the only floor of an elevator which is almost free from grain dust without the aid of the dust collecting services. Due to its great height, splendid views of the enormous extent of the flat pampas can be seen from this floor. Figs. 6 and 7 illustrate the ample and well-laid-out head floor of the Rosario South elevator.

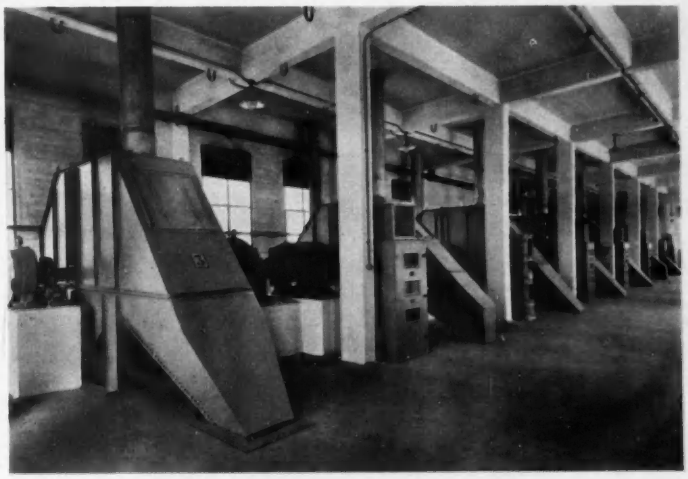


Fig. 7.—Another view of the elevator head floor at Rosario South showing the elevator motors and control pillars.

(*c*) The next floor below (*b*) is entirely devoted to the distribution pipework from the elevator heads to the compensating hoppers. In Quequen this floor is constructed in the form of a well of the elevator head floor. Fig. 8 shows a corner of this floor at Villa Constitucion.

(*d*) Walking down the elevator, or sliding down on poles, similar to those used in fire stations, brings one to the weigher floor, where a great deal of activity takes place. On this floor the enormous weighers of reinforced boiler plate are installed together with their head valves and discharge valves. The central control room also is situated on this floor, with the push button control board for the starting of the motors, the signal-room, the terminal of the pneumatic despatch system, and the operating mechanism of the valves below the elevator heads.

(*e*) Next comes the distribution floor, where the revolving " Mayo " spouts are installed. These divert the grain from the weighers into the required " handling " or " shipping " silos ; also on this floor is the machinery for the treatment of grain residues, handled by the residues elevator from the cleaning floor at ground level. It is interesting to note the great noise created on this floor due to the grain—particularly maize—rushing through the "Mayo" spouts. A glance through the inspection holes reveals that the pipes are polished like silver, and were it not for the special diverting plates used the pipes would be quickly worn away by friction. Considerable heat is generated in these pipes from the passage of the grain.

(*f*) The floor over the working house bins is at the same level as that over the storage bins. Here will be found the long over-bin conveyors (fig. 9) and the interesting travelling throw-off cars which divert the grain from conveyor to silo. The portion over the working house silos is almost a solid mass of fixed spouting for discharge on to the over-bin conveyors. Certain small grain treating machines are also installed on this floor.

(*g*) On reaching ground level after passing the working house bins one arrives at the cleaning floor. On this floor is centralised most of the machinery for grain treatment, i.e. large banks of separating and ventilating machinery, the oat-clipping machines, etc., as well as the large portable spouts, by means of which grain can be taken from working house bins past the cleaning floor without

Fig. 8 (above).—Floor over compensating hoppers at Villa Constitucion.

Fig. 9 (right).—Distribution conveyors over the silos at Rosario South.

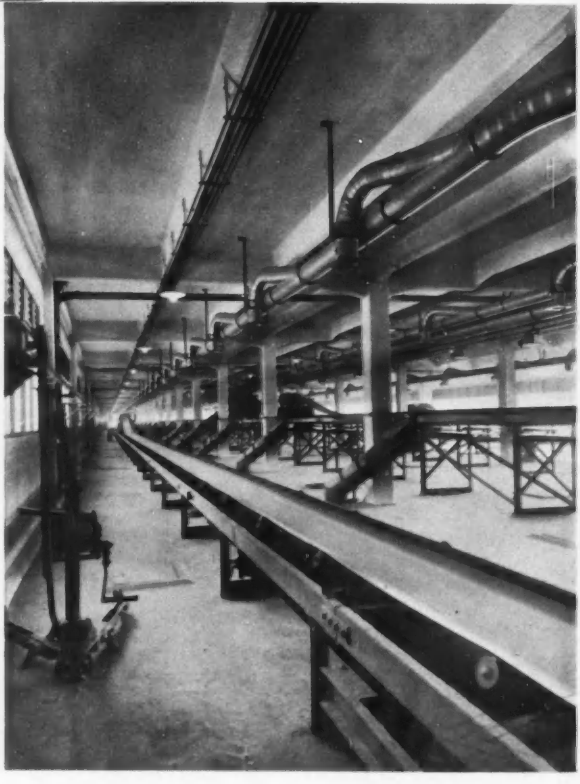
passing through the cleaning machines. Fig. 10 shows one of the 70 h.p. motor drives to the oat-clipping machines.

(4) THE STORAGE SECTION.

The storage section is situated at one side or, in the case of the Quequen elevator, divided into two equal wings on each side of the working house. The section consists of a large number of round-shaped silos and inter-silos built of reinforced concrete. Long conveyors run the entire length of these silos above and below for charging and discharging. At Ingeniero White extension, no fewer than six distribution and twelve extraction conveyors are installed. Fig. 11 shows the driving end of one of the extraction conveyors at Villa Constitucion. In practice each customer has his own bin or series of bins in which his grain is stored awaiting treatment or shipment. A feature of this section is the large blackboard at the entrance of the over-bin floor giving a representation of the silos, the name of the customer whose grain is in the silos and the quantity of grain therein. Samples of the grain stored are taken at frequent intervals and any irregularities, such as fermentation or the entry of destructive insects, are quickly attended to.

(5) THE DRYING SECTION.

A drying section is usually added to elevators which are mainly designed to handle maize, e.g. at Rosario and Villa Constitucion. This section, which consists of four floors, is situated between the working house and the block of silos, the top floor being at the same level as the over-bin floor. The driers consist, briefly, of a honeycomb through which the grain falls from compensating hoppers above into similar hoppers under the honeycomb. As the grain falls by gravity hot air is blown through it, the air being heated by oil-fired furnaces. In each of the elevators mentioned twelve fans are installed in this section driven by 20 h.p. motors, some ten other small motors are also required to operate the adjustable gravity valves and the furnace equipment.



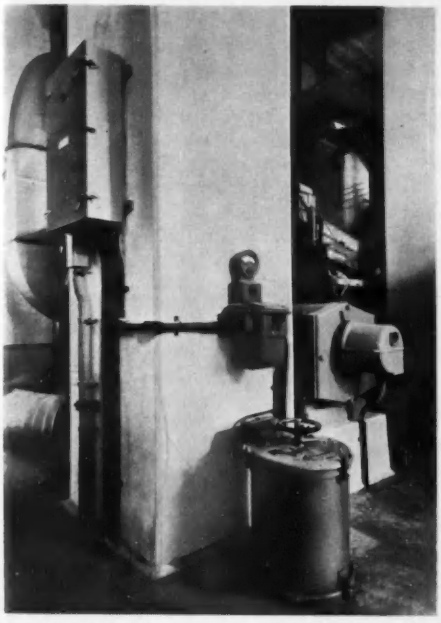


Fig. 10.—The cleaning floor at Rosario South: a 70 h.p. motor and starter for driving one of the oat clippers.

(6) SHIPPING SECTION.

This consists of an inclined approach and shipping gallery of very large proportions, the length in some cases being over 750 feet and the height almost equal to that of the silos. The compensating hoppers, the loading-out stations, seven or eight in number, together with the winch operated telescopic discharge spouts for grain shipped in bulk, as well as the spiral chutes and slide-ways for bagged grain and the automatic sack-filling machines are located in the supporting towers. This section is one of the most interesting of an elevator during the loading-out period. The arrival of a ship is a common local sight and the only interest aroused is to observe what flag she carries. Almost before the vessel is tied up the grain is pouring into her holds, the men on board signal to the winchman to direct the spouts at the required angle, cut off the supply of grain in order to direct the flow at another angle, or to transfer the loading to another spout. Meantime on the quay the ship is being loaded with provisions, and high in the gallery the samplers are busy with their long-handled cone-shaped sampling scoops collecting the samples of grain which are approved before the ship sails. Loading being almost complete, the flow of bulk grain is stopped and the cargo is "topped-up" with bagged grain in order to prevent shifting of the cargo. The men start to work at the sacking machines; they work with surprising rapidity and no sooner are the sacks full than they are sewn up and go sliding down the chute into the almost full hold. Fig. 12 shows the driving end of four of the conveyors in the shipping and inclined shipping gantries of Rosario South.

A plan of an elevator of the terminal type is seen in fig. 13.

ELECTRICAL INSTALLATIONS.

As already mentioned, the major portion of the electrical equipment was supplied by the G.E.C., each new elevator being provided with its own transformer substation, either situated apart from the main body of the

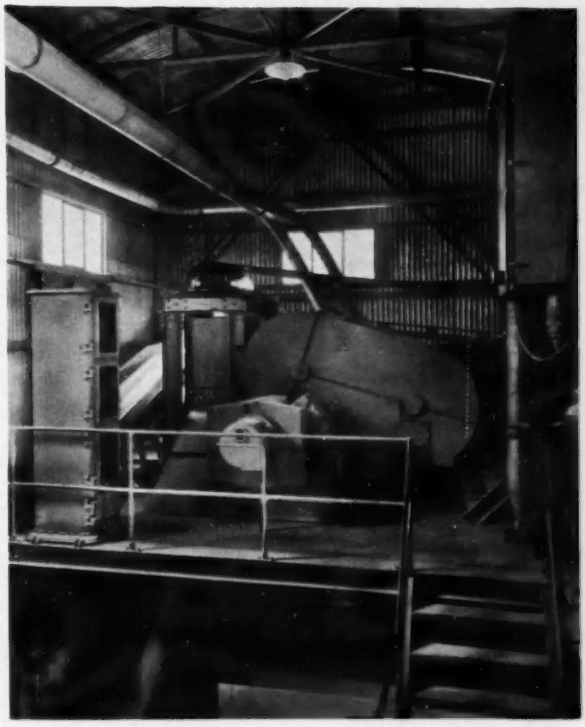


Fig. 11.—Motor and starting pillar operating an extraction conveyor at Villa Constitucion.

elevator building or, in the case of Quequen, between the working house and one wing of silos. The substations are supplied with current by the local supply authority and house the high tension switchgear, power and lighting transformers, low tension and lighting switchboards.

The high tension switchgear supplied for Rosario South and Villa Constitucion is of the cubicle type 11 kV and 13·2 kV respectively, each switchboard comprising six panels, i.e. incoming panel for dual supply, three power transformer panels, one lighting transformer panel and a potential transformer panel. An interesting feature of these boards is the very complete system of mechanical interlocking of the incoming isolators with the transformer isolators by a "Castell" key device. Fig. 14 illustrates the Villa Constitucion high tension switchboard; the lighting switchboard may also be seen in the picture. For Quequen, S.V.D. gear is provided with wing isolators at each end for dual incoming supply at 6·5 kV.

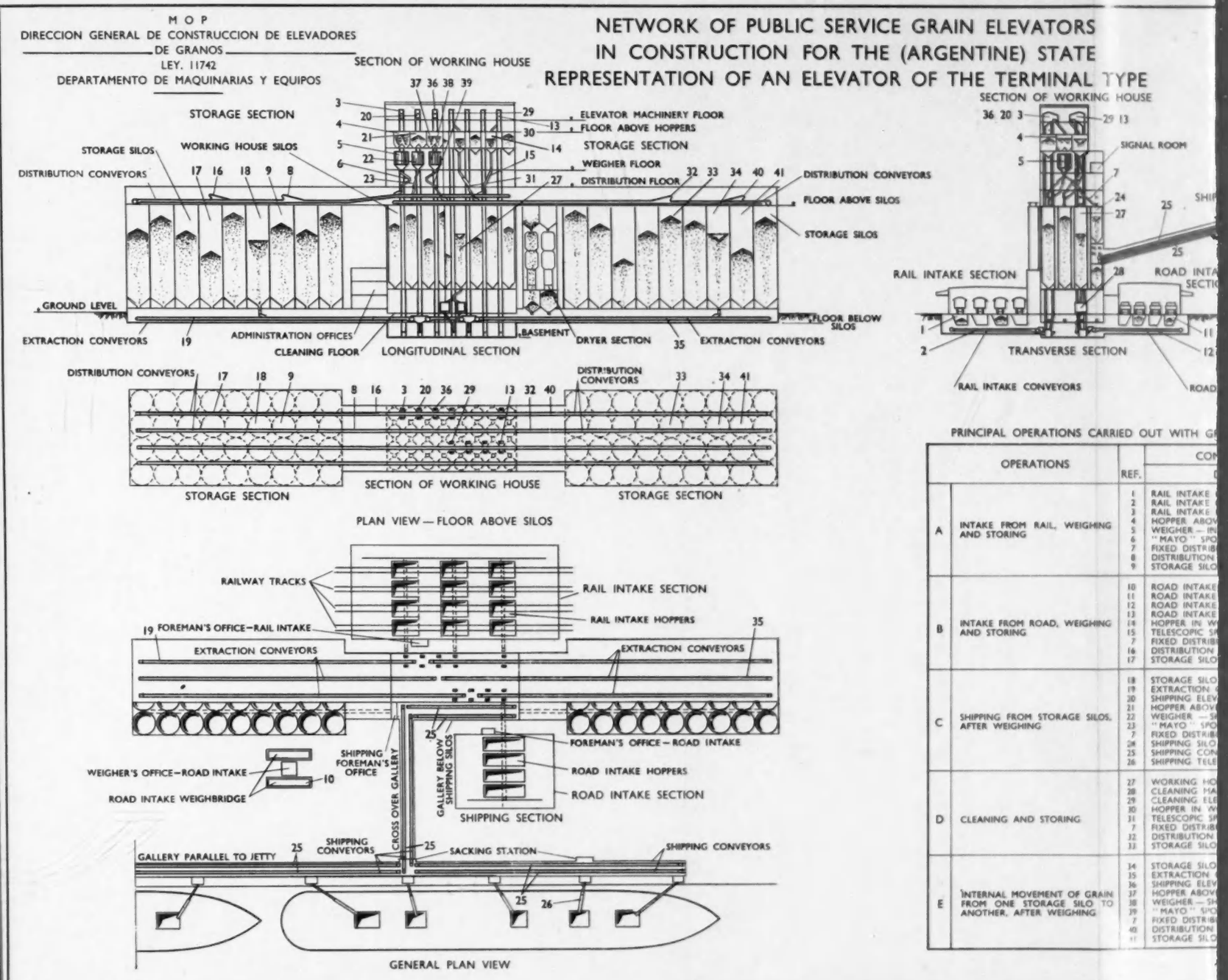
Fig. 12.—The shipping gallery at Rosario South. In the background are seen four starting pillars and, above, a motor driving an inclined conveyor.

Three indoor type, 3 phase, 50 cycle power transformers were supplied in each case for Rosario South and Quequen, rated at 1,100 kVA and giving 380 volts on the output side. Lighting transformers were also provided for these elevators of 150 kVA and 100 kVA capacity respectively. All the transformers being of standard construction do not call for further comment.

The low tension switchgear for Rosario South, Villa Constitucion and Quequen is identical in type, and consists of flat-back steel fronted panels. In the case of the Rosario South elevator the board consists of 21 panels, which due to its great length is installed in two sections at right angles, thus giving a very pleasing appearance in the switch-room. The Quequen board is also of 21 panels. Fig. 15 shows the 15-panel board installed at Villa Constitucion.

For the conveyor drives, elevators, cleaning machinery, fans, etc., 278 motors were supplied in sizes ranging from 3 h.p. to 180 h.p., the aggregate power of these machines amounting to some 8,587 h.p., screen protected types being favoured for all drives in spite of dusty conditions, the fine dry dust having no detrimental effect on the machines. Squirrel cage, high torque motors were provided for practically all drives up to 35 h.p. and slipring type above this size. All motors are fitted with a fine wire mesh at the openings to prevent the entry of vermin and in addition the slipring motors have a glass inspection window in the slipring cover.

The control gear for the motors is of the automatic type, excepting that for the 75 h.p. oat clippers and the machinery winches, and is of very robust construction, direct-to-line starting being used for the squirrel cage motors and contactor rotor resistance starters for the remainder. All starters are provided with a two-position lock-out device to enable a selected line of elevators and conveyors to start up in sequence on operating a push button at the control board, or for local starting and stopping should the necessity arise. The starters are fitted with adjustable thermal overload protection, between full-load and 200 per cent overload, the thermal strips on the larger starters being transformer operated. Each conveyor is provided at frequent intervals along its length with a lock-out type push button whereby, in

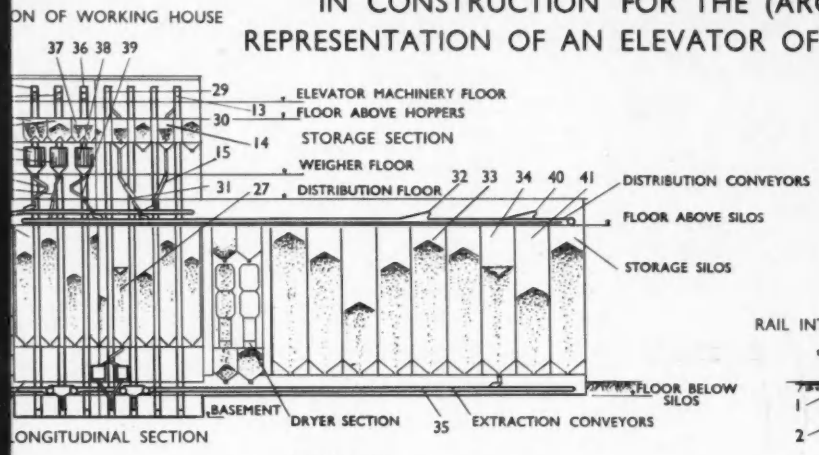


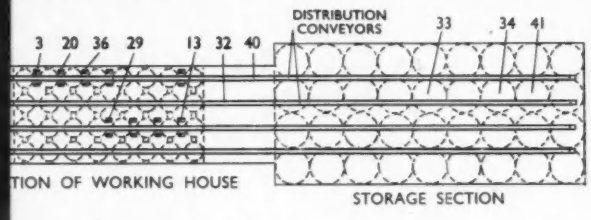
PRINCIPAL OPERATIONS CARRIED OUT WITH GR

	OPERATIONS	REF.	CON
A	INTAKE FROM RAIL, WEIGHING AND STORING	1	RAIL INTAKE
		2	RAIL INTAKE
		3	RAIL INTAKE
		4	HOPPER ABOV
		5	WEIGHER — IN
		6	"MAYO" SPO
		7	FIXED DISTRIB
		8	DISTRIBUTION
		9	STORAGE SILO
B	INTAKE FROM ROAD, WEIGHING AND STORING	10	ROAD INTAKE
		11	ROAD INTAKE
		12	ROAD INTAKE
		13	ROAD INTAKE
		14	HOPPER IN W
		15	TELESCOPIC SP
		7	FIXED DISTRIB
		16	DISTRIBUTION
		17	STORAGE SILO
C	SHIPPING FROM STORAGE SILOS, AFTER WEIGHING	18	STORAGE SILO
		19	EXTRACTION C
		20	SHIPPING ELEV
		21	HOPPER ABOV
		22	WEIGHER — SH
		23	"MAYO" SPO
		7	FIXED DISTRIB
		24	SHIPPING SILO
		25	SHIPPING CON
		26	SHIPPING TELE
D	CLEANING AND STORING	27	WORKING HO
		28	CLEANING HA
		29	CLEANING ELE
		30	HOPPER IN W
		31	TELESCOPIC SP
		7	FIXED DISTRIB
		32	DISTRIBUTION
		33	STORAGE SILO
E	INTERNAL MOVEMENT OF GRAIN FROM ONE STORAGE SILO TO ANOTHER, AFTER WEIGHING	34	STORAGE SILO
		35	EXTRACTION C
		36	SHIPPING ELEV
		37	HOPPER ABOV
		38	WEIGHER — SH
		39	"MAYO" SPO
		7	FIXED DISTRIB
		40	DISTRIBUTION
		41	STORAGE SILO

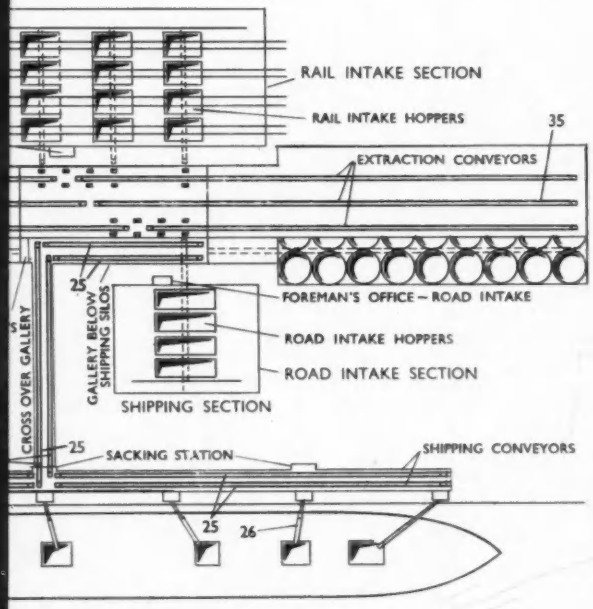
Fig. 13.—Plan of an elevator of the terminal type.

NETWORK OF PUBLIC SERVICE GRAIN ELEVATORS IN CONSTRUCTION FOR THE (ARGENTINE) STATE REPRESENTATION OF AN ELEVATOR OF THE TERMINAL TYPE

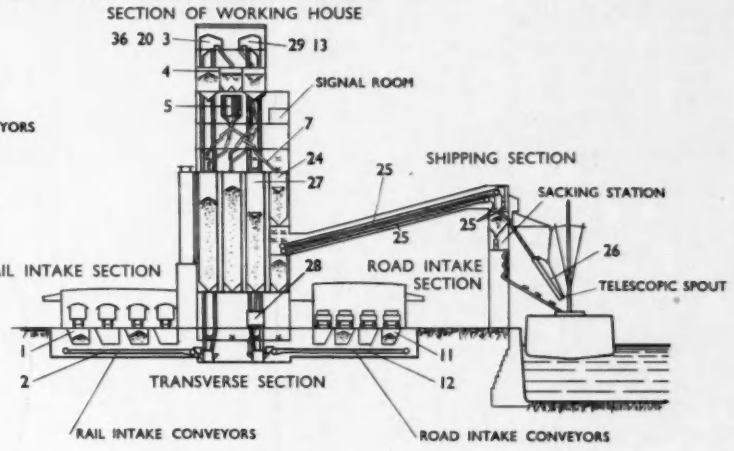




VIEW — FLOOR ABOVE SILOS



GENERAL PLAN VIEW



PRINCIPAL OPERATIONS CARRIED OUT WITH GRAIN IN AN ELEVATOR

	OPERATIONS	REF.	COMPONENTS USED — DESIGNATION
A	INTAKE FROM RAIL, WEIGHING AND STORING	1	RAIL INTAKE HOPPER
		2	RAIL INTAKE CONVEYOR
		3	RAIL INTAKE ELEVATOR
		4	HOPPER ABOVE WEIGHER — INTAKE HOPPER
		5	WEIGHER — INTAKE HOPPER
		6	"MAYO" SPOUT
		7	FIXED DISTRIBUTION SPOUTS
		8	DISTRIBUTION CONVEYOR
		9	STORAGE SILO
B	INTAKE FROM ROAD, WEIGHING AND STORING	10	ROAD INTAKE WEIGHBRIDGE
		11	ROAD INTAKE HOPPER
		12	ROAD INTAKE CONVEYOR
		13	ROAD INTAKE ELEVATOR
		14	HOPPER IN WORKING HOUSE
		15	TELESCOPIC SPOUT
		7	FIXED DISTRIBUTION SPOUTS
		16	DISTRIBUTION CONVEYOR
		17	STORAGE SILO
C	SHIPPING FROM STORAGE SILOS, AFTER WEIGHING	18	STORAGE SILO
		19	EXTRACTION CONVEYOR
		20	SHIPPING ELEVATOR
		21	HOPPER ABOVE WEIGHER — SHIPPING HOPPER
		22	WEIGHER — SHIPPING HOPPER
		23	"MAYO" SPOUT
		7	FIXED DISTRIBUTION SPOUTS
		24	SHIPPING SILO
		25	SHIPPING CONVEYORS
		26	SHIPPING TELESCOPIC SPOUT
D	CLEANING AND STORING	27	WORKING HOUSE SILO
		28	CLEANING MACHINES
		29	CLEANING ELEVATOR
		30	HOPPER IN WORKING HOUSE
		31	TELESCOPIC SPOUT
		7	FIXED DISTRIBUTION SPOUTS
		32	DISTRIBUTION CONVEYOR
		33	STORAGE SILO
E	INTERNAL MOVEMENT OF GRAIN FROM ONE STORAGE SILO TO ANOTHER, AFTER WEIGHING	34	STORAGE SILO
		35	EXTRACTION CONVEYOR
		36	SHIPPING ELEVATOR
		37	HOPPER ABOVE WEIGHER — SHIPPING HOPPER
		38	WEIGHER — SHIPPING HOPPER
		39	"MAYO" SPOUT
		7	FIXED DISTRIBUTION SPOUTS
		40	DISTRIBUTION CONVEYOR
		41	STORAGE SILO

Fig. 13.—Plan of an elevator of the terminal type.

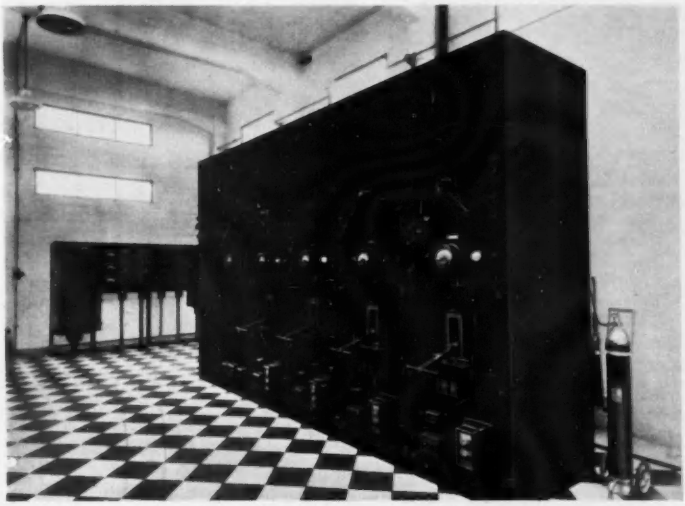


Fig. 14.—The six-panel 13·2 kV switchboard at Villa Constitucion. The main lighting board is seen in the background.

case of emergency, it can be temporarily stopped or locked out of action if desired.

The power supply is distributed by paper insulated, double steel taped, armoured cables on a 380 volt, 3 phase, 50 cycle, 4-wire system to distribution fuse boards located on each floor or section of the building, "non-bleeding" type cable supported on "Wittonite" cleats being used for the long vertical runs. The connections to the motors are made with V.I.R. cables run in conduit, or in armoured cable in the case of the larger motors.

Special attention is paid to the lighting installations, which are designed to give an average illuminating intensity of 30/40 lux[1] at 3 ft. from the floor. The majority of the interior fittings are of the 150 watt size of a very robust type, manufactured by the G.E.C. especially for use in grain elevators. Standard 75 and 100 watt fittings are also installed as well as a number of watertight bulkhead types. There are also several plug points on each floor for easy inspection of the interior of hoppers and silos. The installation is carried out in steel conduit, the accessories, as in the case of the other installations, being of high quality, all-round boxes having rubber gaskets to prevent the entry of dust and insects. The suitable placing of the fittings was found to be a problem in some sections amid the maze of fixed and movable spouting. The lighting fixing brackets and hangers had to be of heavy construction to resist breakage due to continual sweeping by long brooms. In all four elevators a total of 1,800 lighting fittings of different types were installed.

The lightning arrester installation was designed on the theory that a lightning arrester can protect a space limited by the circumscribed parabola, calculations making it necessary to fit four arresters on the working house and up to seven over the silos. These arresters are connected by bare copper stranded cable to different earth plates; in addition, one of every two of the shipping gantry towers on each elevator is connected to its own earth plate in the waterway. Finally each building is provided with a set of red and green aerial navigation lights.

Fig. 15.—The fifteen-panel low tension board at Villa Constitucion.

[1] 1 lumen per sq. ft. = 10·764 lux.

ERECTION OF THE ELECTRICAL EQUIPMENT.

The erection of the electrical equipment was carried out by The Anglo-Argentine General Electric Co. Ltd., the distribution schemes having been prepared in the Buenos Aires office. An idea of the magnitude of the work may be judged by the fact that no less than 160,000 feet of heavy gauge conduit was installed, together with 720,000 feet of V.I.R. cable and 35,000 feet of armoured cable.

AUXILIARY INSTALLATIONS.

The auxiliary installations of these grain elevators are many and varied and are of sufficient importance to warrant further mention :

(*a*) Each elevator is complete with an extensive pneumatic despatch system, similar to that seen in a large department store, for the rapid transportation of written orders between the most important sections.

(*b*) A dust collecting and disposal system is installed, this being one of the most important features of a modern grain elevator, since dust, if not efficiently disposed of, is a serious handicap not only to the working personnel, but incurs grave risks of fire due to its explosive nature ; although it is humanly impossible to keep a grain elevator completely free from dust, these new installations are, in the circumstances, remarkably dust-free. At each grain deviating point where dust is generated a hood is fitted and the dust sucked into a trunking system and carried to the disposal unit ; dust collecting on the floors is swept into suction holes. The importance of the dust collecting services is borne out by the fact that approximately ten per cent of the electrical power used is devoted to this purpose.

(*c*) The fire protection services have to be carefully considered, and in this connection an interesting installation of fire detection apparatus was installed at Rosario South and Quequen. These fire detectors may be seen along the roof in figs. 6 and 7.

(*d*) The administration offices in the vicinity of the elevator form an important block of buildings. Communication between these offices and the working points of the elevator is maintained by a system of private automatic and direct telephones. The welfare of the working personnel is also taken into consideration and the elevator buildings are well provided with wash-rooms and drinking fountains.

FURTHER CONTRACTS.

The writer would like to mention here that Henry Simon Ltd. and the G.E.C. have now received another large contract in Argentina and will equip the great elevator in the Port of Buenos Aires of 150,000 tons capacity. This elevator will be the largest in the Southern Hemisphere and almost equal to the combined capacity of the three new elevators referred to in this article.

It is also interesting to note that, in collaboration with the Argentine Grain Elevator Construction Committee, there was recently completed an interesting installation of audible and visible signalling in the Rosario North elevator, an existing elevator of some 50,000 tons capacity, thus greatly speeding up the handling of grain in that particular building.

CONCLUSION.

The contract for this equipment was undertaken towards the end of 1938. Shipment was made before Lend-Lease became effective, as part of the export drive in support of the war effort. A number of shipments was lost due to enemy action and had to be replaced, causing considerable delay. However, the contract was completed before the end of the war, thus enabling the installations to supply the grain so sorely needed in Europe and elsewhere.

The new elevators have now been operating for some time at full capacity and form the main outlet for the shipping of grain from Argentina to all parts of the world, the Quequen elevator having already shipped more than 4,000,000 tons of cereal of various types.

ACKNOWLEDGMENT.

The author acknowledges with sincere thanks the collaboration of the Argentine Grain Elevator Construction Committee, and their permission to publish the illustrations and diagrams reprinted in this article, and in particular the assistance of Engineer Carlos Vieiro, Acting Director, and of Engineer Leopoldo Fernandez, Chief of the Electrical Department.

Statistical Methods and Engineering Processes

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This paper was presented to a meeting of the Mathematics and Engineering Sections of the British Association held at Brighton on September 13th, 1948, devoted to a discussion on the "Application of Statistics to Engineering". It provides a general expository review of the nature and use of modern statistical methods in relation to a broad interpretation of "engineering industry". It pays special attention to personal as well as technical aspects.

INTRODUCTION.

WHILE interest in the use of statistical methods in the engineering industry was greatly stimulated during the recent war, being markedly encouraged by Government departments subsequent to 1942, it is appropriate to recall the more important contributions made during the preceding twenty years.

The first published evidence of the industrial use of these methods appeared in the Bell System Technical Journal in the early 1920's, and there is evidence that they were also being introduced in at least two large organisations in Great Britain. Sampling clauses indicating a growing appreciation of statistical concepts appeared in British Standard specifications published in the period 1924-1934 and the publication in 1935 of British Standard No. 600, "The Application of Statistical Methods to Industrial Standardisation and Quality Control",[1] epitomised the position at the time. Although a number of useful papers arising out of industrial experience were published in the Journals of several engineering institutions and in the Supplement to the Journal of the Royal Statistical Society during the period 1927-1939, it appears that only a few British manufacturing organisations were using the methods prior to the wartime activity referred to above. In spite of the wartime stimulus, factories using formal statistical methods, either in manufacture or research, are still exceptional and this alone will provide justification for this subject forming part of the deliberations of the Engineering Section of the British Association.

In this necessarily brief expository review of the scope of statistical methods in relation to the engineering industry we shall give a broad interpretation to "engineering". We think this is desirable because of the widespread utilisation of semi-automatic and automatic machinery in industries which would perhaps not normally be considered as falling within the description "engineering industry". We think the correctness of this view will be demonstrated in the section of this paper which describes the part that statistical methods can play in appraising the quality performance of a machine or process.

For convenience, and in order that it shall coordinate later papers presented to this Session, this review is divided arbitrarily into two main sections described as "routine" and "investigatory", and each of these sections is subdivided under the descriptions "product inspection" and "process performance".

STATISTICAL CONCEPTS OR PRINCIPLES.

The fundamental concept underlying many of the statistical methods here considered is that if repeated observations are made of some quantity the value of which is affected by a large number of small chance causes, then the results when collected tend to be grouped about a central value and become progressively less frequent as the divergence from this central value increases. Such a distribution can be described numerically in two ways, illustrated in fig. 1 :

(*a*) in terms of a measure of *general magnitude* and *a measure of spread*.

(*b*) in terms of proportions outside a specified limit or limits (proportion "defective").

The usual measure of general magnitude is the average or arithmetic mean and the measure

of spread is the standard deviation, which is the square root of the average squared deviation from the arithmetic mean. The determination of the precise shape of the distribution curve for the results of observations made on articles produced under a particular set of conditions demands an extremely large number of observations, but in industrial practice it is not usually possible to obtain so many results without some extraneous factor disturbing the conditions. In these circumstances a second statistical concept is appropriate, namely, that an estimate can be made of the distribution of the bulk (or population) from the properties of samples selected at random from it. The appropriate properties of the results for samples are the average for the measure of general magnitude and the range (difference between highest and lowest values) for a measure of spread. The data needed to relate the characteristics of measurements made on samples to the characteristics of the bulk are available in published tables. For example, if ten samples each containing four individuals are measured, the average of all the samples provides an estimate of the average of the bulk and the standard deviation of the bulk can be estimated by dividing the average of the ten values of range derived from the samples by the factor 2·06. Further, the degree of confidence which should be placed on these estimates can be determined by statistical methods. Similarly, if, for convenience, the bulk distribution is described in terms of a proportion defective, or if it is so described because the quality of the product cannot be measured on a continuous scale, then an estimate of this proportion is the average proportion defective found in a number of samples of equal size. For example, if ten samples of twenty contain a total number of twelve defectives the estimated proportion in the bulk is 6 per cent.

The everyday use of the results of observations on samples to guide judgment involves a third statistical concept in order to make proper allowance for the inevitable variability which will be found between the results of samples drawn from the same bulk. This inevitable variability is present both in the average values for the different samples and in the degree of variability in the individual results comprising a sample. Similarly, the number of defectives found in a sample will vary from sample to sample. The data concerning the degree of variability which is inevitable between the results of samples drawn from the same bulk are also contained in published tables. These tables enable the engineer to make due allowance for this characteristic feature of the results for samples when the latter are used to guide the formulation of technical or executive opinion. The practical methods by which these allowances are made will be referred to in later sections of this paper.

ROUTINE USE OF STATISTICAL METHODS

(a) Acceptance Inspection of Products.

This is frequently the most suitable method for introducing the industrialist to statistical techniques because it is traditional practice to

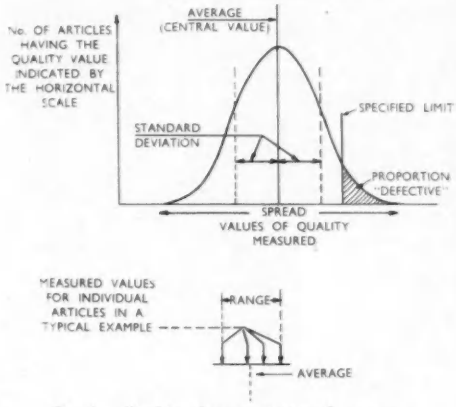

Fig. 1.—Quality characteristics of process.

inspect a product after fabrication to determine whether it is acceptable, or needs correction, or has to be scrapped. Further, it is convenient because the inspection of incoming materials or components will continue to be emphasised until the methods described below are in more general use, thereby enabling evidence of the quality of the product concerned to be made available to the purchaser and the need for acceptance inspection to be considerably reduced. The application of statistical principles to the inspection of products reduces the labour of inspection in appropriate circumstances by substituting the inspection of samples for the usual 100 per cent inspection. However, it is obvious that inspection of a product after manufacture has only an indirect influence on reducing waste of material and labour, and that greater economies can be effected by utilising inspection *during* manufacture to ensure that the process is operating in such a way that the product will be acceptable.

Before considering modern inspection schemes it is necessary to refer to the usual assumption that 100 per cent inspection provides for the complete elimination of defective material. In practice, because of inevitable differences be-

tween testing, methods, gauges, and personnel, unanimity of opinion after 100 per cent inspection is not consistently attainable. In the authors' opinion, for a large class of goods which serve as components to assemblies, if the proportion of unsatisfactory product can be reduced to less than one per cent it constitutes a practical interpretation of "no defectives to specification". If this be accepted, then the modern acceptance inspection schemes can be made of more general application than if a strict interpretation of "no defectives" be arbitrarily adopted. Further, it should be noted that if inspection schemes which involve less inspection can be adopted it is likely that the inspection of the smaller amounts of material will be more effectively carried out than under the conditions of fatigue and boredom imposed by continuous 100 per cent inspection.

Acceptance inspection can be conveniently divided into two classes: to one class belong those methods by which a batch or consignment of goods is accepted or rejected; and to the other class belong those schemes by which the amount of unsatisfactory material in a batch or consignment is reduced to an acceptable value. This latter class has been called "Rectifying Inspection Schemes", the former being referred to as. "Acceptance Sampling Schemes".

(i) Acceptance Sampling Schemes.

These schemes are best suited to those products where the cost of inspection is high or where inspection is particularly inconvenient. If it be insisted that the consignment contain no unsatisfactory product, no sampling scheme is applicable. Further, should evidence be available that the quality of the material is controlled at a satisfactory level then acceptance sampling schemes are, strictly speaking, unnecessary and only occasional check-testing by relatively small samples is desirable to promote confidence in the evidence of control. Similarly, if there is evidence that the product is in control but that the proportion of unsatisfactory material is too high, the product is unacceptable, and acceptance sampling schemes should not be used. If used, they would on occasion accept batches which were of no better quality than those rejected.

Acceptance sampling schemes are applicable when a product is acceptable which contains less than a defined proportion of unsatisfactory material and the quality of the batches offered may be better or worse than that required. However, it should be remembered that in schemes of this kind involving the acceptance or rejection of batches of material on the result of testing samples, batches containing too much defective material will occasionally be accepted and, conversely, satisfactory batches will occasionally be rejected. Such risks are inherent in all sampling schemes but their magnitude can be defined on statistical principles.

Acceptance sampling schemes can be broadly classified as 'single', 'double' and 'sequential'. Single and double acceptance sampling schemes have been in use for some time, whereas sequential schemes have been recently developed, both for acceptance sampling and rectifying inspection, largely by Professor Barnard when working in the Ministry of Supply. Similar work was done independently by American statisticians at about the same time. Of the various acceptance sampling schemes the simplest in operation are those where a decision is arrived at after a single sample has been inspected. The other schemes show advantages in cost of inspection for a given guarantee of quality, but additional organisational costs tend to be associated with their use. However, these schemes frequently appeal to manufacturers because additional tests are made before deciding on rejection. This may tend to encourage their use more than may be economically justified. Hence, in all cases where acceptance sampling schemes are applicable each problem should be considered on its merits, but schemes based on statistical principles will enable correct appraisement to be made of the economy involved.

(ii) Rectifying Inspection Schemes.

The fundamental distinguishing feature of these schemes is that they aim at accepting as much as possible of the material produced. They are suited to those products which are easily and economically tested or for which the demand considerably exceeds the supply. As in Section (*i*) "Acceptance Sampling Schemes", these schemes are not applicable if no unsatisfactory articles can be accepted, and are unnecessary should evidence be available that the quality of the material is controlled at an acceptable value, in which case only a relatively small amount of check testing is necessary. Possibly the simplest application of a rectifying inspection scheme would be to a *controlled* product for which evidence is available that it contains a higher proportion of unsatisfactory material than is acceptable. In such cases it is obvious that by inspecting a sufficient proportion of the product, and removing the unsatisfactory articles, the proportion of unsatisfactory articles in the accepted material can be reduced to the required value. Rectifying inspection schemes are applicable when the quality of the batches offered varies and may be

better or worse than that required. A simple scheme consists of examining a sample of predetermined size and on the result of this examination deciding whether to accept, without test, the remainder of the batch, or to subject a sufficient proportion, or all of the remainder, to 100 per cent inspection.

An example of such a simple rectifying inspection scheme was described in detail by Dodge and Romig in 1929. The same authors have since published a double sampling scheme which effects further economies in inspection, particularly when the batches are large and the proportion of defective material is small. The value to the industrialist of the schemes described by Dodge and Romig resides in the thoroughness with which they have been prepared, the ready availability of the tables,[2] and in the approval with which they have been met where they have had considerable use in industry. As already indicated, some rectifying inspection schemes have more recently been suggested which are referred to as " sequential " schemes but they are not readily available in a form suited to use by the industrialist and for that reason there is little practical experience with such inspection schemes.

(b) Quality Performance of Processes.

The word " process " is used advisedly. In this connection a process is an operation which yields a product to which a measure of quality can be applied, the results of such measurements being amenable to pictorial presentation in the form of a chart and/or to statistical treatment. For example, a lathe can be used for turning a cylindrical body, boring a hole, or cutting a length ; the kind of tools and the method of holding them may vary, and the operation may be carried out automatically or through the medium of operators. Each of the possible combinations may be considered as a process and the production engineer needs to know the quality performance of the process and in particular the variability associated with it. Hence the industrialist is primarily concerned with manufacturing processes set up to achieve definite objectives and a method is needed for measuring the quality of a process and for determining whether or not it is constant or stable as manufacture proceeds. The statistical technique commonly referred to as " Quality Control " satisfies these requirements. This technique concentrates attention on the processes and utilises the broad statistical principles referred to earlier in this paper.

As the quality characteristic of an individual specimen of a product can be expressed in two ways, either by describing it as satisfactory or defective to a standard or alternatively by direct measurement, there are consequently two methods of describing the quality characteristic of a process : by the fraction or proportion defective and by the frequency distribution of the results of individual measurements. These quality characteristics of a process can be expressed numerically ; the fraction defective

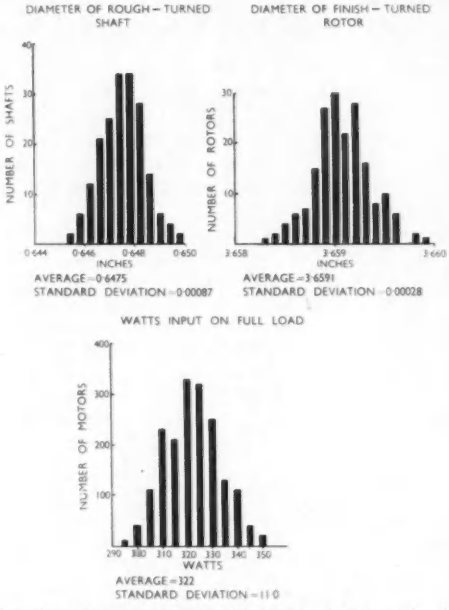

Fig. 2.—Quality characteristics associated with the manufacture of fractional horsepower electric motors.

usually as a percentage, and the frequency distribution of measurements by the central value (average value) and by a measure of spread or variability (standard deviation). In the practice of Quality Control Technique a standard quality characteristic for a process is estimated from the examination of a sequence of small samples selected *whilst the process is operating in a manner which is considered satisfactory by competent technical staff*, without the necessity of actually measuring sufficient product to determine directly the quality characteristic. The number of defects observed in each sample or, where direct measurement is the criterion, the average value and range covered by the results in each sample are noted and by the use of simple rules and tabulated data[3, 4, 5, 6] a numerical estimate of the quality characteristic of the process is made from a sequence of ten to twenty samples. Whether or not the quality characteristic remains

constant, i.e., whether or not the process is stable as time proceeds, is determined by continued inspection of similar small samples selected at approximately regular intervals. Comparison with the established standard, expressed numerically, is made by plotting these sample results on control charts. On these charts are indicated the standard values of quality together with limits appropriate to the amount of variability which is inevitable in the results for such samples selected at random from a bulked product of standard quality, thereby providing the means of making due allowance for the variability inherent in the results for samples. These limits are introduced to assist in differentiating between *apparent* differences which would be present in the results for samples selected from the product even if the process continued to operate in its normal manner and *real* differences in the results which should be regarded as due to changes taking place in the process.

The foregoing discussion is illustrated by the following examples :

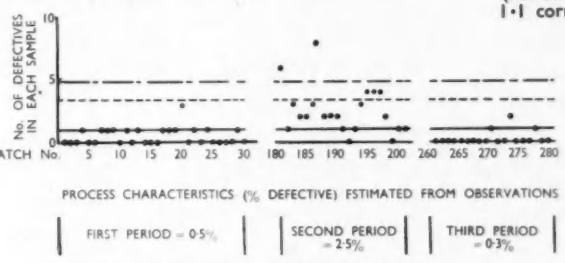
No. OF DEFECTIVES IN EACH SAMPLE
10
5
0
BATCH No. 5 10 15 20 25 30 180 185 190 195 200 260 265 270 275 280
PROCESS CHARACTERISTICS (% DEFECTIVE) ESTIMATED FROM OBSERVATIONS
FIRST PERIOD = 0·5%
SECOND PERIOD = 2·5%
THIRD PERIOD = 0·3%

Fig. 3.—Control chart for defectives.

(i) Quality Characteristics of Processes.

Fig. 1 illustrates in an idealised form the quality characteristic (frequency distribution) of a process. The average and standard deviation, or the proportion defective, by which the characteristic can be expressed, and the values of the average and range for a typical sample are indicated. Fig. 2 illustrates the quality characteristics of typical processes in the form of frequency distributions. The corresponding estimates of the numerical values of these characteristics are stated.

(ii) Quality Control Chart for "Defectives".

The number of defectives found in a sample of 100 articles selected from successive batches of incoming components for inspection under an acceptance inspection scheme are plotted in Fig. 3. The standard quality characteristic was set at 1 per cent defective. This is indicated by the full line on the chart, and the appropriate control chart limits are indicated by dotted lines. The chart shows that the quality of the product was initially satisfactory, that it deteriorated, but subsequently improved. The estimated quality characteristics for the three periods are indicated.

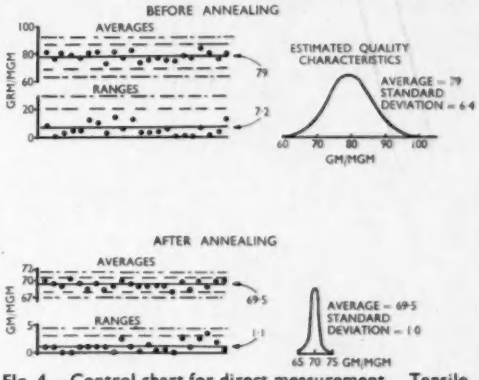

Fig. 4.—Control chart for direct measurement. Tensile strength of tungsten wire. Samples of two specimens. (For samples of two specimens average ranges of 7·2 and 1·1 correspond to standard deviations of 6·4 and 1·0 respectively.)

(iii) Quality Control Chart for Measurements.

In fig. 4 the average and range (i.e., difference) of the tensile strength test results of samples of two lengths of metal wire, selected daily before and after an annealing process, are plotted. The standard values of the respective process characteristics are shown as full lines on the charts for average and range together with the appropriate limits for a sample of two specimens. The estimated process characteristics corresponding to these standard values are shown as frequency distributions. The charts show that all the processes prior to the annealing process, and the annealing process itself, are stable both in respect of central value and variability ; that is, the variability in the result of tests made during a period of about three weeks was no greater than would be experienced if a corresponding number of sample selections had been made from one day's product. As expected on technical grounds the average strength of the annealed wire is less than that of the unannealed wire, but these charts show that the annealing process greatly improves the uniformity of the product, the object for which it was introduced.

Fig. 5 shows a control chart for measurements of eccentricity of small finish-turned rotors.

Eccentricity of rotor affects some of the characteristics of the finished motor and, during the period preceding that shown on the chart, modifications of the process were made until a satisfactory standard value of the average eccentricity was attained. The adjustments made to the process in order to maintain control are noted on the chart. On the right of the chart the first results obtained after making another technical change in the process are included to illustrate when alteration of the control limits to correspond to a better level of quality is appropriate. As a matter of interest, the average level attained by the use of a fundamentally different, but more expensive method (grinding), is indicated.

Fig 6 illustrates the control chart for another process associated with the manufacture of the same article and is an example of the process variability being sufficiently small compared with the specified tolerance to allow of some variation in average level.

This is catered for by the use of "modified" control limits for the sample averages, which are wider than the strict control limits, and are directly related to the limits specified for individual specimens[3, 4].

The foregoing discussion and illustrations support the contention that quality control technique provides information on the state of processes and demonstrates why the estimates of the quality characteristics of processes are of value, although the processes are not used for long runs on precisely the same kind of article. To emphasise this feature of quality control technique a summary of the numerical values of process variability (the standard deviation of the quality characteristics) for a variety of processes is given in the following :

(*i*) *Standard deviation of diameter of the body of a small shell turned on multi-spindle lathes.*

(Average value, approximately one inch.)

Tooling method A, machine no. 1, 0·0015 inch
Tooling method A, machine no. 2, 0·0064 inch
Tooling method B, machine no. 1, 0·0092 inch
Tooling method B, machine no. 2, 0·0142 inch

The information on variability contained in such a concise presentation of data as the above will be of obvious value to those concerned with design, production planning, machine maintenance and purchase.

(*ii*) *Standard deviation of weight of coating sprayed on a small component before assembly*

(Average value, approximately 5 milligrammes.)

Process as first set up 0·45 milligrammes

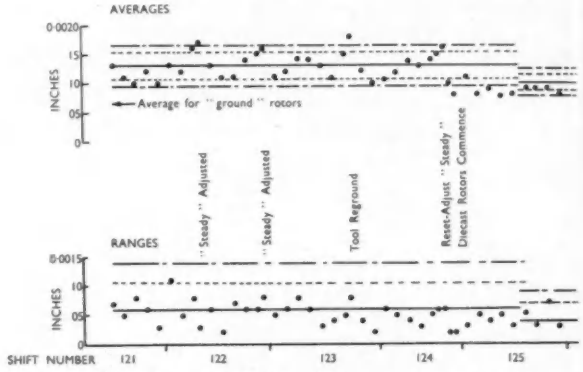

Fig. 5.—Control chart for fractional horsepower electric motors. Eccentricity of finish-turned rotor. Sample size 5.

After intensive study to improve the process 0·08 milligrammes

(*iii*) *Standard deviation of monthly loss in percentage units of a main component during an assembly process.*

(Average value, approximately 5 per cent).

From daily records kept by manufacturing groups—average over all groups 0·10 units per cent.

From records of overall supply of components and stock of assemblies kept for purpose of cost accountancy 0·55 units per cent.

While the different nature of the two methods of obtaining these data could be accepted as sufficient reason for the difference in the two values of variability they nevertheless indicate that individual monthly losses obtained for cost purposes cannot be considered as wholly determined by conditions of manufacture during corresponding periods.

(c) General Comments on the Routine Use of Statistical Methods.

It is not possible in a brief review to describe fully the applications of quality control technique at the various stages in the manufacture of an engineering product involving a number of processes. It is hoped, however, that the examples chosen and those to be given in later papers will serve to illustrate how a relatively

small amount of sample inspection carried out at various stages of the manufacture serves not only to provide information to guide the technical control of the processes concerned, but also serves to exert control on important functional characteristics of the final product. It is also claimed that such methods provide assistance of a kind not inherent in the normal methods of technical control. The factual record of events occurring during the operating of a plant presented by quality control charts is of profound value. This record reduces, if it does not eliminate, incorrect adjustments made by reason of faults of memory wrongly associating cause and effect. Where production difficulties are encountered, the existence of quality control charts makes it more difficult for those responsible for a process to camouflage the real origin of the trouble by plausible, though often specious, argument in order to concentrate enquiry or to place blame elsewhere—a process often referred to as "passing the buck". Experience has shown that in the long run the establishment of quality control technique in a manufacturing organisation improves the relationships between the individuals concerned. Inspectors at all levels who, under the old regimes, are primarily concerned with "scrapping" product and are a source of *criticism* of the production effort come to be recognised as providing direct *assistance* to the manufacture of acceptable product. Again, as manufacture is frequently organised in sections, the end product of one section serving as the starting material for another, the exhibition of the control charts for the various manufacturing stages creates a better mutual understanding between the responsible technicians in the sections and promotes a sense of joint responsibility in a common task. Stated in another way, the practice of quality control corrects tendencies for local measures of quality and efficiency in sections to be set up which are not consistent with the manufacturing efficiency of the organisation.

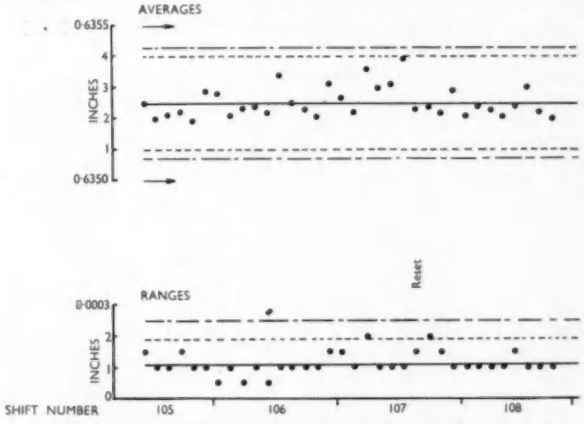

Fig. 6.—Control chart for fractional horsepower electric motors. Diameter of bore of sleeve bearing. Sample size 5.

Quality Control becomes a common language for all concerned in the factory, from the operator, through all degrees of supervisory staff, to the executive management. While operators are not called on in any way to understand the details of control chart technique they quickly appreciate its objective, and experience has repeatedly shown that considerable improvements in quality result, not by reason of technical changes, but solely by interest created in tasks which may otherwise provide little satisfaction to the operator other than that associated with the pay packet. The existence of a common language in the form of a control chart helps operators to appreciate the essential part they play in the manufacture of a product which will give satisfaction in service. Similarly, the executive management is not called on to be familiar with the details of the quality control chart technique, but to comprehend the principles which govern its operation in order to make wise provision for its application because of the part it plays in co-ordinating the efforts of the manufacturing force to achieve the economic production of a satisfactory product.

THE USE OF STATISTICAL METHODS IN INVESTIGATIONS.

(a) Inspection of Product.

An important, but not consistently recognised, aspect of inspection either for process control or for acceptance purposes, is the variability of the measurements involved. Intelligent appreciation of the contribution made by the process of measurement to variability in the results of observations of product quality is essential to the efficient working of control systems and to the correct application of specifications.

In the case of routine measurements undertaken for manufacturing control purposes the magnitude of the variability, associated with repeated measurements of the same article at any one time and with measurements involving the set-up of apparatus from time to time, may be estimated by the observer making repeat measurements on a few articles or on suitably

prepared sub-standards and studying the results by control chart techniques. By plotting on control charts the results of such measurements made on sub-standards at regular intervals, the process of routine measurement can be maintained at an accuracy adequate to the particular application. In most cases it is desirable that measurements on sub-standards set aside specially for the purpose should occasionally be made under both the routine conditions and under conditions where an appreciably higher accuracy of measurement is possible; for example, in a standardising laboratory or specially equipped tool-room. By plotting the differences between these measurements on a control chart the absolute level of the routine measurements can be scrutinised.

Where conformity to specification is concerned, it is usual for measurements to be made both by producer and consumer under what may be termed "commercial conditions"; that is, different pieces of measuring apparatus made for general sale have to be used by skilled observers rather than by trained technicians. In these circumstances, in addition to the variability of measurements made by one observer on one instrument, account may have to be taken of variations arising from one or more of such causes as the following:

(*i*) differences between the measuring instruments or machines;
(*ii*) differences between observers;
(*iii*) differences between instruments and/or machines from one occasion to another.

Estimates of the magnitude of these variations can be made by applying the statistical technique known as the "Analysis of Variance" to the results of simple planned experiments in which a few articles or samples of material are measured in a number of establishments on a number of different occasions. Where the identical material cannot be measured twice, the experiment can be planned to minimise the effect of changes, such as trends, in the properties of the materials tested.

The Analysis of Variance technique enables the total variation of observations to be analysed into estimates of the contributions to variability associated with the various factors (this corresponds to the estimate of a quality characteristic from small samples) and enables tests to be made to distinguish between *apparent* differences which are inevitable in the averages of a small number of observations and *real* differences arising from changes in apparatus and/or observers (this corresponds to the use of control limits in quality control). The following will serve as an example.

Tensile testing machines in four establishments were involved in measurements for elongation of nickel wire, and measurements were made on a number of samples of wire interchanged between the four establishments on a number of occasions. On each occasion, a number of measurements was carried out on each machine. Statistical analysis of the results enabled the following statements to be made:

(*i*) the inherent variability corresponding to repeat measurements on any machine on one occasion could be represented by a standard deviation of 1·2 in units per cent;
(*ii*) the variability from occasion to occasion for any one machine could be represented by a standard deviation of 1·0 units per cent;
(*iii*) differences existed between the gross average levels of the four machines corresponding to deviations of +1·5, −1·5, +0·5 and −0·5 units per cent from the average level of all four machines.

Such information can be used in a variety of ways. Thus, if measurements were being made in one establishment, e.g. at the manufacturing plant solely with the object of maintaining quality at a satisfactory level, items (*i*) and (*ii*) would be involved but the systematic errors expressed in item (*iii*) would not. (If the product had been one in which the same article could be measured a number of times, then the correction of daily set-up by the use of these as standards would remove the influence of item (*ii*).)

However, this example involves tests to specification by both producer and consumer, and checks by an independent authority. In these circumstances, systematic differences between testing machines can cause serious misunderstanding. Estimates of the magnitude of these systematic differences enable adjustments to results to be made, but it is important to realise that this would not eliminate the effect of the variations from occasion to occasion which will appear as a variable difference between machines on any one occasion, unaffected by any amount of averaging of repeated measurements on that occasion.

In the foregoing example, factors have been considered which may arise when considering variability in measurements involving a number of instruments, each associated with only its own particular observer. In national specifications it is clear that the problem becomes more complex as other factors, such as changes of observer, demand consideration.

(b) Development of Processes.

An additional value of the use of quality control technique using direct measurement is that it provides factual data which are suited to statistical investigations leading to the modification and improvement of processes or to the setting-up of new ones. Such investigations require a general knowledge of statistical methods as well as good technical knowledge of the processes concerned. The control charts, apart from the direct value of the data recorded and their use as a basis for investigation, constitute an important background for planned experimentation, which in turn may modify the procedure adopted for the purposes of quality control. The statistical techniques used in such studies will generally involve the use of Analysis of Variance which has already been referred to, and Regression Analysis which seeks to establish the degree of correlation between two or more properties of a product or, for instance, the efficiency of a plant and the efflux of time. Regression Analysis will be of value, for example, in studying the relationship between two qualities of a product, one of which is more readily measured than the other, or between the functional quality of an assembly and the quality of one or more of its components.

It is difficult to over-emphasise the importance of combining statistical knowledge with sound technical knowledge and the following example will serve to illustrate the need for this. The data illustrated in fig. 7 are the test results obtained on the product of a machine making articles on twelve different " heads ". An inspection, by the engineer in charge, naturally suggested that head number five was producing poor work and required attention, and further statistical analysis of the results comparing the variation between the means of the twelve heads with the variation within the heads would confirm this. However, knowledge of the construction of the machine suggested that heads 1-6 and 7-12, should be grouped as shown in the figure, under " left " side and " right " side. The question now to be answered is : " Does the difference between the two side means indicate a fault in the associated mechanisms and/or does head no. 5 need attention ? " A formal analysis using this knowledge of the design of the machine showed, in fact, that head no. 5 was not at fault, since all " head " means

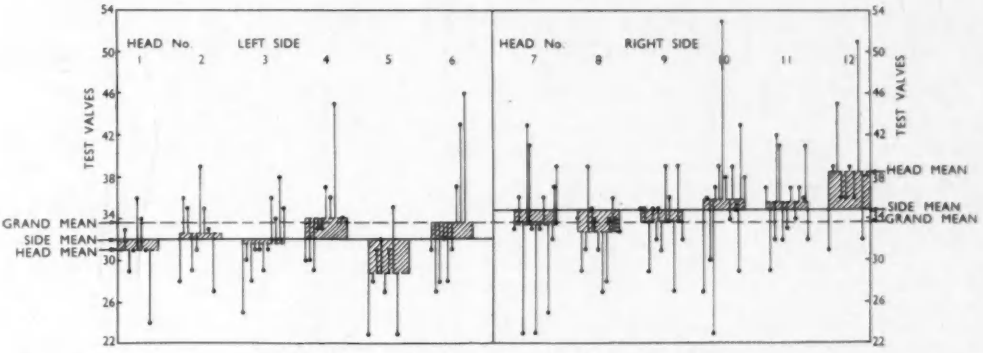

Fig. 7.—Test results for product of multi-head machine.

were statistically consistent with the particular " side " means with which they were associated, but that the left-hand side was producing work significantly lower in average value than the right-hand side. The essential features of the analysis are given in the Analysis of Variance Table on p. 84. The values of the ratios of the associated estimates of variability (mean variances) given in the table have to be compared with corresponding values (significance levels) given in published tables[7] for such ratios, which might occur due merely to chance. This comparison shows that the variation of the " head " means from the " side " means is smaller than might be expected, while the difference between the two " side " means exceeds that which might be expected due to chance.

The practical interpretation of this result is that something common to all heads on the left-hand side should receive attention and that the individual heads should not be disturbed. Without the formal analysis any technical man would almost certainly have given attention to head no. 5, leaving the whole of the left-hand side to produce work at a lower level of quality than the right. Unfortunately, because the low value for the product for head no. 5 was due to chance, it is highly probable that later data

would have convinced him that the attention given had had the desired effect. On the other hand, without knowledge of the operation of the machine, a statistician could not have been expected to have gone further than the stage in the analysis in which head no. 5 compared unfavourably with the other eleven heads. It is perhaps apposite to remark here that if data be grouped in a manner inconsistent with the technical feature of the work, or if data be subdivided arbitrarily and conclusions drawn without due reference to statistical significance the conclusions may justify the comment that statistics can be made to prove anything.

The above is a relatively simple example and in practice more complex problems will arise involving a multiplicity of variables demanding an appreciation, not merely of the effect of each variable considered separately, but of the interacting effects of two or more variables with one another. The statistical techniques can be extended from the simple example discussed in the foregoing to the complete analysis of complex experiments and will be essential if anything like a rational solution devoid of oversimplification is to be obtained.

However, the engineer-statistician would be well advised to aim at achieving a reasonable degree of statistical stability in the processes with which he is concerned before passing on to consider the more complex relationships which may exist in manufacturing processes.

ANALYSIS OF VARIANCE TABLE.

Source of Variation	Sum of Squares	Deg. of freedom	Mean Variances	Variance Ratio, F.	Significance levels of F.	
					0·5	·01
Differences between sides	233	1	233	233/27·1=8·6	3·9	6·9
Differences between heads within sides	392	10	39·2	39·2/27·1=1·4	1·9	2·5
Differences within heads	3,139	116	27·1			
Total	3,764	127				

(c) General Comments on Statistical Methods in Engineering.

It is fitting, at the risk of repetition, to conclude by drawing attention to two important principles which must not be overlooked. The successful operation of a manufacturing procedure demands considerable experience and detailed knowledge of machines and processes. If this experience is associated with specialised knowledge of physics and chemistry few will dispute that the engineer so equipped is better able to fulfil his function in industry than one depending solely on engineering knowledge and experience. Similarly, if to these accomplishments the engineer can add a working familiarity with the principles of statistics he will still further enhance his value to industry. The use of statistical technique alone cannot solve problems demanding a knowledge of physics, chemistry, or engineering, but it can serve as a powerful aid when drawing conclusions from technical data. The example discussed above will serve to support this argument. Emphasis has, of course, been placed, in this discussion, on the study of manufacturing processes, but it should be recognised that the principles are of general application to problems which arise in diverse industrial activities such as research experimentation and the interpretation of data derived in the course of administration, such as figures of productivity and sales.

Finally, a warning should be sounded against any inclination to believe that acquisition of the techniques discussed can be achieved merely by listening to papers on the subject or reading text-books. No one has become a skilled exponent of a game by reading books, but many have become skilled by combining concentration of mind with practice. The practice of statistical methods, associated with a keen appreciation of the principles involved, will alone give the engineer command of this valuable tool.

REFERENCES.

1. B.S. 600—1935 : " The Application of Statistical Methods to Industrial Standardisation and Quality Control ", by E. S. Pearson. (The British Standards Institution—London.)
2. " Sampling Inspection Tables ", by H. F. Dodge and H. G. Romig. (Chapman and Hall, London.)
3. B.S. 600R—1942 : " Quality Control Charts ", by B. P Dudding and W. J. Jennett. (British Standards Institution. London.).
4. " Quality Control Chart Technique when Manufacturing to a Specification ", by B. P. Dudding and W. J. Jennett, (The General Electric Co. Ltd., England.)
5. " A First Guide to Quality Control for Engineers ", by E. H. Sealy. (H.M.S.O.)
6. B.S. 1313 : " Fraction-Defective Charts for Quality Control ". (British Standards Institution, London.)
7. " Industrial Experimentation ", by K. A. Brownlee. (H.M.S.O.)

The High-Voltage Laboratory, Witton Engineering Works

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INTRODUCTORY.

THE High-Voltage Laboratory at the Engineering Works, Witton, was originally completed in 1930 when the main items of test equipment installed were a 750 kV power frequency cascade-connected transformer set and a 1,000 kV surge generator. A detailed description of this equipment and the scope of the investigations undertaken at that time has already appeared in these pages.[1]

In November, 1940, the Laboratory was severely damaged by enemy action and a large part of the equipment destroyed. The task of rebuilding and re-equipping was begun immediately and, by the end of 1941, the Laboratory was again in full working order. Since very considerable extensions were made to the equipment it is considered opportune to describe the Laboratory in its present form and also the advances made since the original installation in the application and measurement of extra high voltages.

The functions of this section of the Development Department may be divided broadly into two categories. First, it provides the specialised information required for the design of high-voltage apparatus, and second, undertakes type, and certain routine, testing of the Company's equipment for use on high-voltage systems. The large variety of technical data and operating experience accumulated during the years that the Laboratory has been in operation have provided a sound basis for drafting test specifications for all types of high-voltage equipment, and much of this information has been passed on to the British Standards Institution.

Before the last decade, standard specifications and acceptance conditions in general called only for certain well-established power-frequency over-voltage tests and no piece of completed equipment was subjected to a test voltage in excess of two and a quarter times its normal rated value. While, during its working life, such equipment is not likely again to be so highly stressed at the power frequency, it may be subjected to dangerously high surges due to lightning, having a peak voltage far in excess of this value. This is particularly so if the apparatus is directly connected to exposed high-voltage transmission lines. It follows that more recently the subject of testing by surge voltages has acquired ever-increasing importance.

A lightning surge is usually steep-fronted, i.e. it may rise to its peak voltage in less than one microsecond; it may, however, persist for several hundred microseconds. Since there is no theoretical limit to the voltage which may develop from a lightning discharge, it is neither economical nor practical to design equipment which alone is proof against the higher lightning surges. By the judicious use of surge protective devices, however, such discharges can be partially diverted to earth by a safe path, to the extent that the greatly reduced overvoltage remaining is innocuous to the connected apparatus.

At the present time various committees are considering the details of surge testing schedules to be included in the proposed revised editions of the appropriate British Standards, and it is likely that final agreement will not be long delayed. These additional over-voltage tests are intended to establish an adequate and economic level of electric strength against lightning surges, to standardise types of apparatus for use on high-voltage systems and, by the correct co-ordination of insulation between the various items of equipment, to ensure a prolonged and trouble-free service life.

Surge investigations have been undertaken at Witton Engineering Works for nearly twenty years, and when the Laboratory was rebuilt particular attention was given to the comparatively new technique of full-scale surge testing of completed equipment. The experience gained in the intervening years was invaluable in the design and installation of the new 2½ million-volt surge generator with its associated

[1] *G.E.C. Journal*, Vol. 1, No. 4, February, 1931, p. 161.

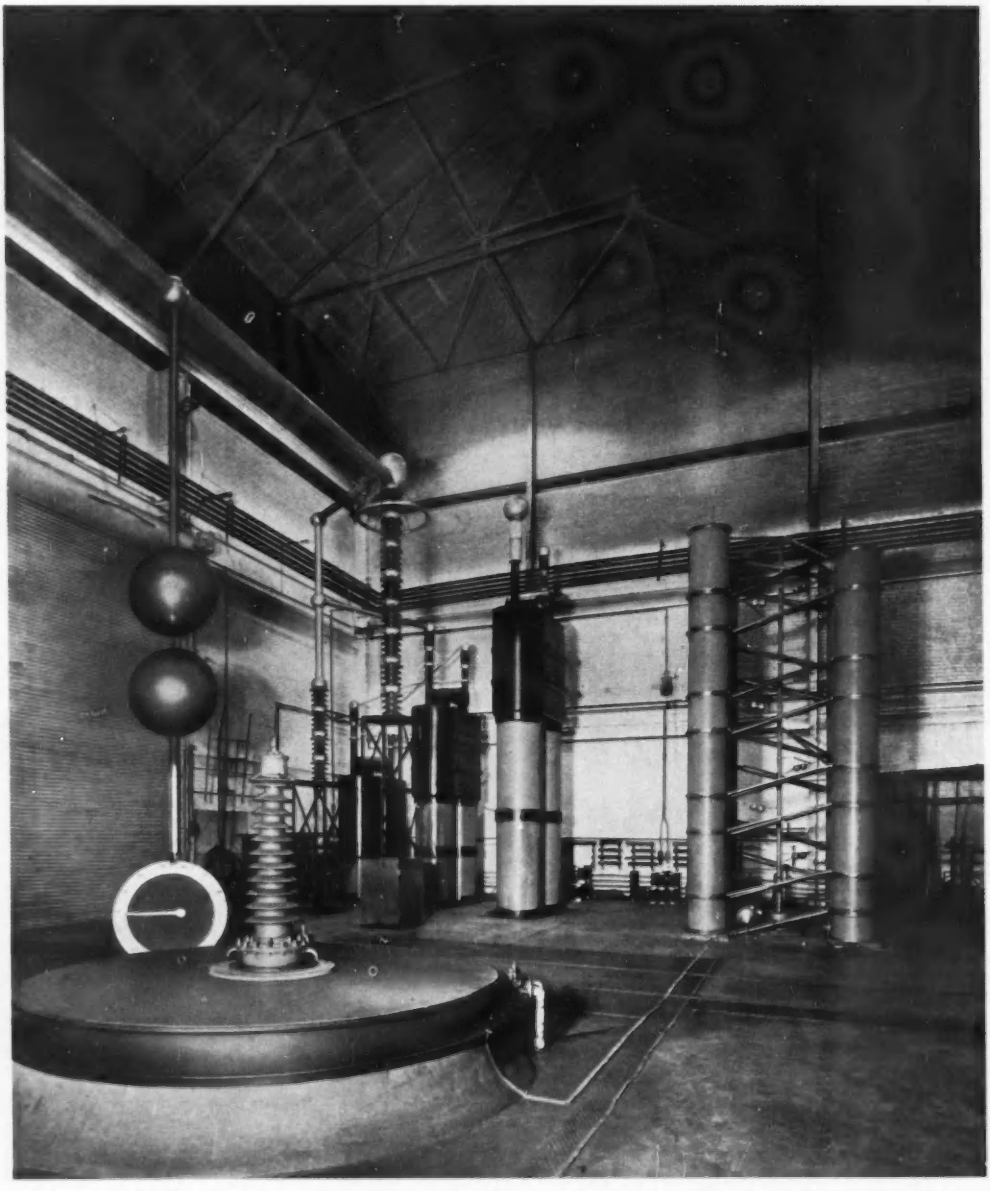

Fig. 1.—The High-Voltage Laboratory showing, on the left, 750 kV cascade connected transformers for testing at power frequencies and, on the right, the 2,500 kV surge generator.

equipment. At the same time the opportunity was taken to rearrange the 750 kV, 50 cycle cascade transformers, sphere gap and busbars, to permit type and routine tests to be made on equipment rated at 264 kV and above.

A general view of the new Laboratory (fig. 1) shows the cascade transformers, sphere gap and busbars on the left and the surge generator with its D.C. charging unit on the right.

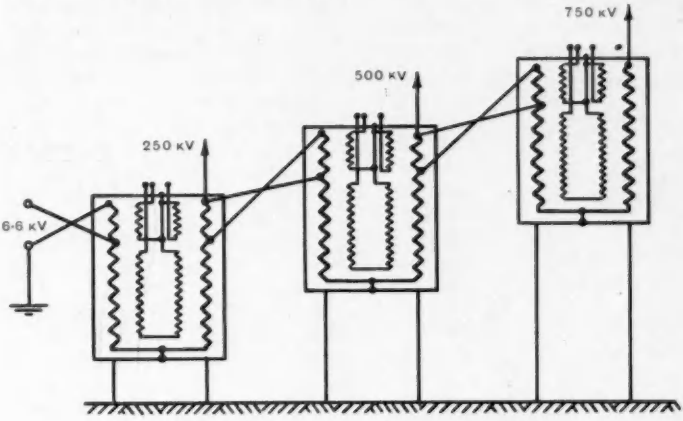

Fig. 2.—750 kV cascade transformer connections.

TESTING TRANSFORMERS.

High voltages at power frequency are obtained from three identical single-phase auto-wound transformers arranged for cascade connection as shown in fig. 2. Each transformer is rated at 100 kVA, 6·6/250 kV r.m.s., making available a maximum test voltage of 750,000 volts. The transformers are oil-immersed with the centre point of the winding connected to the tank which is mounted on synthetic resin impregnated paper cylinders to give the necessary insulation to earth. For more flexibility at the lower voltages, one or two transformers only may be used which merely necessitates rearrangement of the light alloy interconnecting links between the units. A resistance of 100,000 ohms is inserted between the output terminal of the transformers and the main busbar to limit the short-circuit current consequent upon a flash-over or breakdown of the test object. This consists of a paxolin tube filled with water which is easy to maintain and has a high heat capacity for conducting one-minute withstand tests.

The 6·6 kV primary winding of the test transformers is excited from a 1,000 kVA alternator and the voltage is controlled by regulation of the exciter field. Instantaneous overload trips supplied from current transformers operate the main circuit breaker. A general view of the cascade transformers and busbars is shown on the left in fig. 1.

A 1,000 kVA over-insulated transformer with a split secondary winding is arranged to give voltage outputs up to 78 kV r.m.s. and is also controlled from the main control panel. This transformer is used to excite, at the power frequency, test objects which at the same time are being subjected to surge voltages, and is of particular importance in the development of surge diverters.

A 5 kVA, 50 kV transformer, arranged in an enclosed area, complete with its own protective gear, is used for breakdown tests on oil samples and thin dielectrics. It is also used for conducting life tests on insulation and surge diverters.

Any one of these transformers may be connected to the main busbar which is supported on post insulators at a height of 30 feet above floor level, and is used to suspend the upper member of the calibrating spheres.

WET TESTING EQUIPMENT.

To investigate the behaviour of insulators under wet conditions a mobile rain spray is used, consisting of two banks of six nozzles each, all of which are infinitely adjustable. The nozzles are arranged on an H framework which can be raised or lowered on a vertical steel joist and also tilted through a number of fixed angles. The water for the tests is obtained by mixing condensed process steam and local mains water to give the required resistivity of 9,000-11,000 ohms per centimetre cube. After mixing it is pumped into a tank in the Laboratory roof, which affords an almost constant head of 50 ft. at the nozzles. The resistivity of the water flowing to the spraying nozzles is continually checked by a resistivity meter mounted on the main power-frequency control panel. The water is passed through a glass tube into which are sealed two platinum electrodes. The resistance of the water between these electrodes is used as one arm of an A.C. bridge circuit, and is balanced against a variable resistor calibrated directly in ohms per centimetre cube. Balance of this bridge is indicated by a "magic eye" tuning device.

OIL TANK.

At one end of the test area is an oil tank, 11 ft. diameter by 12 ft. deep, set into the

Laboratory floor and equipped with steam heating coils. In this tank tests may be carried out upon articles totally immersed in oil at any desired temperature.

SURGE GENERATOR.

The surge generator was designed with two aims in view : namely to provide a high output voltage and large electrostatic capacitance. The first requirement is essential in order to be able to investigate the surge strength of equipment intended for use on the extra high-voltage systems ; the second is necessary in order to maintain a good voltage waveshape when testing high-capacitance test objects, such as large transformers.

The generator is built on a unit construction to form a sixteen-stage modified Marx generator, the circuit arrangement of which is shown in fig. 3. Each stage comprises a 0·2 microfarad condenser having a maximum working voltage of 160 kV, a 16,000 ohm charging resistor R_C, a wavefront resistor R_F, a wavetail resistor R_T and a 12·5 centimetre diameter interstage sphere gap.

Each condenser unit comprises two hundred and forty 3-microfarad power factor correction type paper dielectric spools, arranged, four in parallel, sixty in series, on three panilax trays. These trays are supported in a paxolin cylinder with brass end castings, and the completely assembled units are vacuum impregnated and filled with petroleum jelly.

All the resistors are non-inductive, wire-wound, clip-in type, and units having various ohmic values are available for producing several standard waveshapes at various load impedances. The generator, shown in fig. 4, is assembled as a four-column structure, each column consisting of four condenser units spaced by paxolin cylinders fitted with brass end castings in a similar manner to the condensers. Between the columns are insulated bracing struts which also support the interstage resistors and sphere gaps. The overall dimensions of the generator are 10 ft. by 10 ft. base and 25 ft. high. Particular attention is paid to the generator earthing system which consists of twelve $\frac{3}{8}$ inch diameter copper rods driven 30 ft. into the ground at the base of the structure and interconnected with the general Laboratory earthing system. The output voltage is raised or lowered from the cathode ray oscillograph cubicle by simultaneously adjusting the setting of the sixteen interstage sphere gaps between the limits 0 to 7 cms. by the rotation of a motor-driven central column. One sphere of each gap is connected by a rigid link motion to this column in a manner which provides smooth gap control over the whole range.

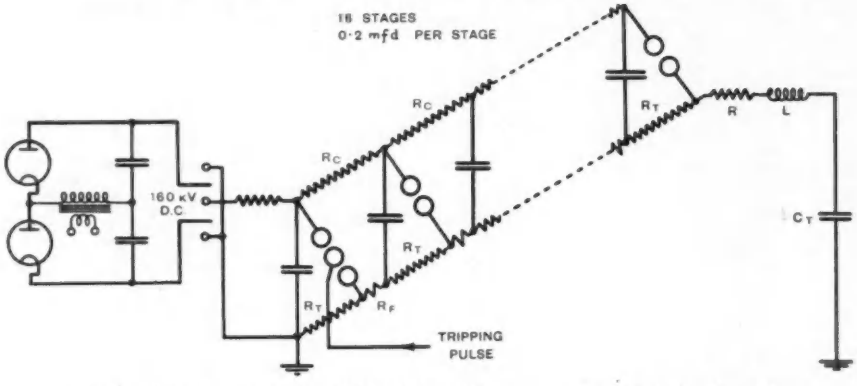

Fig. 3.—Circuit arrangement of 2½ million-volt surge generator and charging unit.

When the generator is arranged with all the condensers discharging in series, its electrostatic capacitance is 12,500 micro-microfarads, giving a maximum open-circuit voltage of 2,560,000 volts. This arrangement provides an available charge of 30 millicoulombs and a discharge energy of 40,000 watt-seconds.

When testing high-capacitance test objects, or for heavy current investigations, the generator may be re-connected in several series-parallel combinations by short-circuiting the interstage resistors with heavy copper bars and opening up the appropriate sphere gaps so that they do not spark over. For example, with all sixteen stages arranged to discharge in parallel the electrostatic capacitance is 3·2 microfarads, and with an output voltage of 160,000 volts the available charge is 500 millicoulombs.

The first stage sphere gap differs from the

remainder in that it is used to trigger the generator by one of two methods which are discussed later.

While currents having a peak value of 80,000 amps. have been obtained from this generator through low-impedance test objects, it was specifically designed for high-voltage investigations. To increase the field of research into surge protective devices, a heavy current surge generator is now being constructed. This will comprise thirty 1-microfarad, 50 kV condenser units, which will be built up in parallel to provide discharge currents in excess of 200,000 amps.

The high-voltage D.C. unit for charging the generator condenser units to their maximum voltage of 160 kV and either polarity is also used for general D.C. testing up to 200 kV. This unit, connected as a voltage doubler circuit, consists of two glass envelope, 220 kV inverse voltage diodes each mounted on a fully-insulated filament transformer, a 230 volt/80 kV input transformer and 0·015-microfarad centre-tapped doubler condenser. The polarity of the output voltage is selected from the oscillograph cubicle by the remote control of a motor-driven change-over switch. The circuit arrangement is shown on the left of fig. 3.

HIGH-FREQUENCY GENERATOR.

A small power frequency energised Tesla coil, having an output of 500 kV at 100 kc/s is used for crack detection in porcelain insulators and similar tests. Both primary and secondary windings are oil-immersed, with the former inside the latter to give a compact arrangement. A primary capacitance of 0·005 microfarads is used for tuning, and the primary is excited through a spark gap having a forced draught between its electrodes.

CALIBRATING SPHERE GAP.

Voltage calibration for 50 cycle tests is carried out by means of a pair of 100 centimetre diameter brass spheres in conjunction with the gap settings given in British Standard No. 358 (1939). The upper sphere is suspended from the centre of the busbar by a paxolin tube filled with water to form an extra resistance to minimise surface burning at the gap. The lower sphere, supported on a steel column running in bearings and passing into the floor, may be raised or lowered by a motor drive through a pulley system which, in turn, operates an indicating arm over a 3 ft. diameter dial, enabling the spark-gap setting to be read at a distance. The control for the sphere gap motor is on the main control panel and is sufficiently flexible to give an average opening or closing speed of 50 cms. per minute, but also permits the gap to be set to an accuracy of 0·5 millimetre. The arrangement of the sphere gap and busbar is such as to permit the full use of a 10 ton crane over the whole of the Laboratory for the preparation of heavy test objects and general maintenance.

SCHERING BRIDGE.

Dielectric loss and capacitance measurement of bushings and similar apparatus are made by means of a 200 kV Schering Bridge, using one of the test transformers and a 100-micro-microfarad compressed-nitrogen-filled standard condenser enclosed in a Texolex cylinder.

HIGH-VOLTAGE HIGH-SPEED OSCILLOGRAPH.

To observe and record the transient phenomena in surge testing, a high-voltage high-speed cathode ray oscillograph is used. This instrument was designed and constructed in the Laboratory.

Fig. 4.—General view of surge generator.

A polished aluminium cold cathode in the discharge chamber at the top of the oscillograph is excited at a potential of 60 kV D.C. with respect to the earthed water-cooled copper anode. The resulting electron beam passes through a 0·25 millimetre diameter hole in the anode block to the trap chamber. Here it is deflected into a lead cup by applying a potential difference to the pair of trap plates. When it is released by an incoming impulse the beam passes into the deflection chamber. One of the two pairs of deflection plates is normally used for the time sweep and the other pair for the surge voltage or current to be measured. The electron beam is sharply focused on to a fluorescent screen at the base of the deflection chamber by means of a concentrating coil fitted with specially designed pole pieces.

To record photographically, the fluorescent screen can be raised to expose the special thin emulsion film on which the electron beam impinges. Extension spindles on the spools enable the film to be wound on, and twelve exposures, each measuring 8 by 6 centimetres, may be taken on one film.

The oscillograph is continuously evacuated by an oil-immersed rotary backing pump and two oil vapour diffusion pumps connected in series which produce a vacuum of 10^{-4} millimetres of mercury. The degree of vacuum is ascertained prior to exciting the discharge tube by means of Geisler tubes.

The 60 kV D.C. cathode potential is obtained from a voltage doubler unit employing metal rectifiers which are capable of supplying a continuous current of 2 milliamperes at 75 kV.

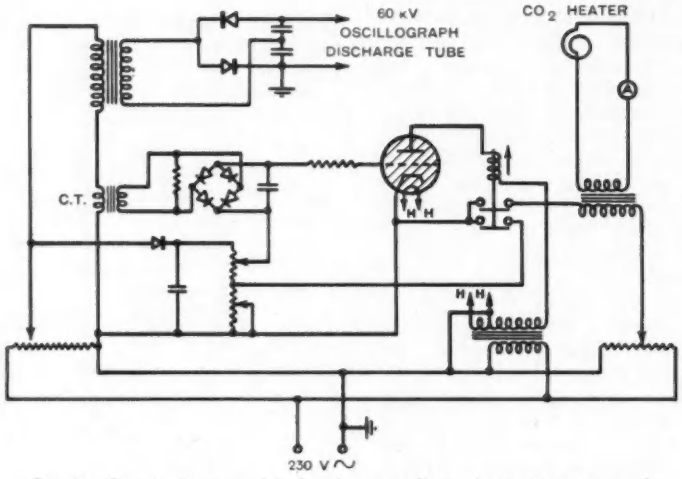

Fig. 5.—Circuit diagram of high-voltage oscillograph sensitivity control.

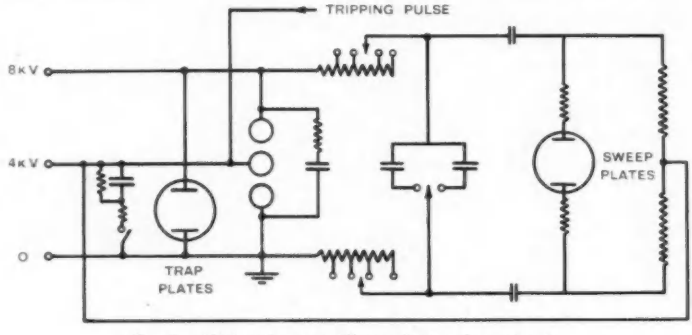

Fig. 6.—High-voltage oscillograph time base circuit.

In order to produce the required intensity of the electron beam it is necessary to allow a small amount of gas to be present in the discharge tube, and its control is very critical if a constant deflection plate sensitivity is to be maintained. In this oscillograph the more usual air-leak method is replaced by an automatically controlled gas generator producing carbon dioxide by heating anhydrous calcium carbonate. The input to the heating element, which determines the quantity of gas produced, is controlled electronically by the discharge tube current in the manner given in fig. 5. A rise in the tube current caused by the generation of too much gas reduces the heat supplied to the calcium carbonate ; this reduces the generation of gas and restores the current to its previous value. The control can be set to give a constant sensitivity for long periods of operation with the tube currents at any value between 0·5 and 1·5 milliamperes.

The single sweep time base circuit, shown in fig. 6, operating at 8 kV, provides a non-linear sweep with the potential of the two deflection plates arranged symmetrically with respect to earth. By a suitable combination of condenser and non-inductive resistors, time sweeps varying from 1 to 5,000 microseconds are available. The energised, three-electrode gap is triggered by an impulse received from the surge generator which collapses the trap plate voltage allowing the electron beam to enter the deflection chamber and starts the sweep.

Auxiliary equipment includes a 1,500 volt D.C. calibrating supply, a crystal-controlled oscillator and a high-vacuum pre-drying film chamber which permits rapid repumping of the oscillograph after a new film is inserted. The four deflection plates are connected to a pair of multi-contact switches which permit any voltage, current, sweep and calibrating parameter to be selected at will.

Fig. 7 shows the oscillograph, with the surge generator control panel on the extreme left.

For rapid and continued observation of high-speed transients a portable sealed-off high-speed cathode ray oscillograph, operating at 6 kV, is more convenient and, moreover, is portable. The time sweep circuit is similar to that shown in fig. 6 and provides sweep speeds between 2 and 3,000 microseconds.

Since the maximum potential difference that may be applied to the deflection plates of the oscillographs is 1,500 volts, a resistance or capacitance potential divider is used to record the high-voltage phenomena. The circuit diagram of a typical resistance divider in use is shown in fig. 8. The high-voltage unit R_1 is built up from a number of non-inductive wire-wound sections, each rated at a maximum working voltage of 500 kV. The low-voltage section R_2 which is variable in ten equal steps is made part of the matching impedance to eliminate reflections in the delay cable, which is also similarly matched at the oscillograph end.

The accurate measurement of surge currents up to 80,000 amps. presents considerable difficulties, since the self- and mutual-inductances of shunts and leads must be kept extremely small. The most satisfactory design of heavy current shunts used in the Laboratory is a fan-type construction consisting of up to twenty twisted loops of wires having their ends sweated to central copper rings. The screened oscillograph leads are brought out orthogonally from the centre of the shunts and incorporate the series matching impedance.

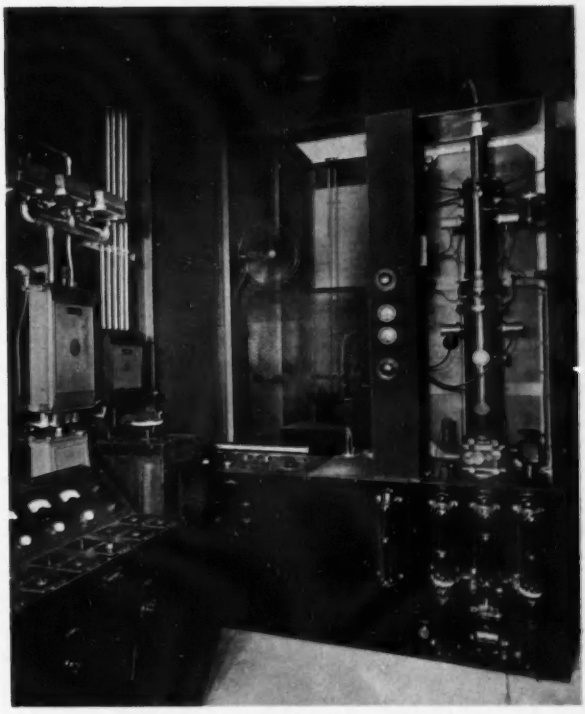

Fig. 7.—High-voltage oscillograph cubicle.

RECURRENT SURGE OSCILLOGRAPH.

For investigations into the distribution of surge voltages in transformer and machine windings a low-voltage recurrent surge oscillograph is used. This has an incorporated surge generator producing a 0·3/80 microsecond wave having a peak value of 300 volts. This is synchronised with the time sweep and recurs at a frequency of 1 kilocycle per second. The complete oscillograph is mounted on a rubber-tyred truck for easy transportation to any part of the Works.

760 mm. of mercury, 20 degs. C. and 11 grammes of water per cubic metre. In the cases in which the maximum voltage to be applied to the test object is not initially known, calibration may be made at two or more voltages as the investigation proceeds. Following calibration, the sphere gap is opened up and the test voltage raised to the desired value.

For wet tests on outdoor gear the rate of precipitation of the water is measured by means of a standard Meteorological Office gauge. This is placed, in turn, at points corresponding to the

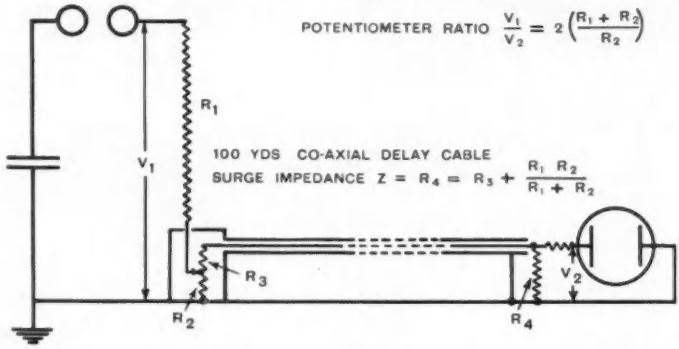

Fig. 8.—Circuit diagram of potential divider and delay cable.

METHOD OF MAKING POWER FREQUENCY INVESTIGATIONS.

The most common investigations made at power frequency are to determine the one-minute withstand, visible discharge, and thirty seconds wet withstand voltages of completed equipment ; and the instantaneous breakdown voltage of prototype apparatus and composite dielectric components. The procedure is very similar in every case and may be generalised as follows.

For those tests in which a specified voltage is to be applied the calibration of the primary circuit voltmeter is made at a voltage 10 per cent less than the test value. The test object, which is usually equivalent to a capacitive load, is connected for the calibration, since it chiefly determines the circuit voltage regulation. The one-metre sphere-gap spacing is set in accordance with the values in British Standard No. 358, and the power frequency voltage is then applied at a uniform rate of 5 kV r.m.s. per second, until sparkover of the sphere gap occurs, when the voltmeter reading is recorded. This is repeated, in all, five times and the mean voltmeter reading used to calculate the meter constant. The atmospheric temperature, pressure and humidity prevailing at the time of test are recorded and, where applicable, used to correct the constant to standard conditions, i.e.

top, centre and bottom of the test object. The mean of the three values, which must not differ by more than 25 per cent, is generally required to be 0·2 in. per minute, and the average angle of precipitation 45°. The area sprayed by the water has also to comply with certain conditions and is proportional to the overall dimensions of the test object.

METHOD OF MAKING SURGE INVESTIGATIONS.

The methods adopted in surge testing and oscillographic recording are, in general, more complex than their power frequency counterparts, chiefly by reason of the short-time duration of the phenomena concerned. Moreover, the parameters of the test object materially affect the waveshape of the voltage produced by the surge generator. Hence the first requirement is to adjust the resistance, inductance and capacitance of the control circuit in relationship with those of the load to obtain the desired waveshape. The usual shape for general voltage tests is 1/50 microseconds in accordance with British Standard No. 923 (1940), i.e. the surge voltage attains its maximum value in one microsecond and decays to half-value in fifty microseconds. The general form of this voltage having

a peak value E_o may be expressed in the form $KE_o\ (e^{-at}-e^{-bt})$ where K, a and b are constants determined by the circuit parameters. The time taken for the surge to reach its peak value is controlled by the constant a, which is a function of the load capacitance C_T, series resistance R and inductance L (see fig. 3). The time taken for the voltage to decay is controlled by the value of b, which is a function of the total circuit capacitance C, the tail resistance R_T and the load impedance. In order that the waveshape shall be free from oscillations on its peak it is further required that the total series damping resistance shall be greater than $2\left(\frac{L}{C}\right)^{\frac{1}{2}}$. It has been found that greater freedom from extraneous oscillations is obtained if the series resistance is partly divided between the sixteen stages and the remainder lumped in the output lead. Once the desired waveshape has been obtained the peak value of the output voltage is controlled from the oscillograph cubicle and its variation does not affect the shape of the wave.

The accurate and consistent recording of surge phenomena depends largely upon the controlled co-ordination of the surge generator and oscillograph operation. Since the time element involved is measured in fractions of a microsecond, this control has to be entirely automatic. For general voltage investigations the recording is initiated by the firing of the surge generator which occurs when the stage charging voltage reaches the sparkover value of the sphere gaps. An aerial placed in close proximity to the first stage gap transmits a pulse to the oscillograph when the generator fires ; this pulse releases the electron beam and starts the sweep. As this takes about 0·3 microsecond it is necessary to delay the arrival of the surge to be recorded at the oscillograph for at least this period.

A low-loss, air-spaced coaxial cable having a characteristic impedance of 100 ohms and low attenuation is used for this purpose ; about one hundred yards being necessary to obtain the required delay.

When it is required to apply a surge to a test object which is simultaneously subjected to its rated power frequency voltage a second method of co-ordination is adopted. This is necessary, since in order to obtain the most stringent test condition the surge must be applied when the sinusoidal power frequency voltage is near to a peak of the same polarity. The circuit which is used is represented in fig. 9. A peaking transformer T_1 is fed through an infinitely adjustable, constant voltage, phase shifting device from a small generator integral with the power testing transformer's exciting alternator. When this

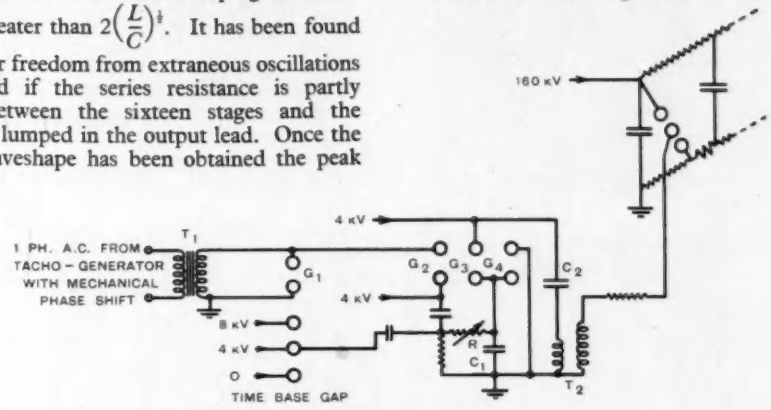

Fig. 9.—Surge generator tripping control.

circuit is closed the secondary voltage causes gaps G_1 and G_2 to fire, which trips the time base starting the oscillograph sweep. At the same instant the condenser C_1 is charged through R and fires the three electrode gap G_3 and G_4. This permits the charged condenser C_2 to discharge through the primary winding of the impulse transformer T_2 whose secondary applies up to 30 kV to the centre electrode of the first stage gap of the surge generator, causing it to fire. The time interval between the tripping of the oscillograph and firing the surge generator can be adjusted over a wide range by means of the variable resistor R. For consistent operation it is necessary that the gap G_1 irradiates the oscillograph time base gap and that G_2 irradiates G_3 and G_4, which, in turn irradiates the surge generator gap.

Various factors influence the precise method of conducting surge tests on particular types of high-voltage equipment. Up to the present time, final agreement between the various technical committees concerned has not been reached on the details of the proposed surge tests to be included in revised standard specifications. No wide divergence from the methods employed

in the very considerable amount of full-scale surge testing that has already been undertaken is anticipated, however. Some typical test methods for various types of equipment are given below :

(*a*) *Cables*. In this case the applied withstand voltage is calculated from the formula 4·5 ($E+10$) where E is the rated line-to-line r.m.s. voltage of the cable. (66 kV for the oil-filled cable under test.) The waveshape is adjusted to 1/50 microseconds in accordance with British Standard No. 923 (1940) and the test consists of the application of ten positive followed by ten negative waves at the test voltage, in this case 342 kV (peak). Since the time required to prepare the cables for test is comparatively long and this work must be done in the Laboratory, it is carried out at night. The electrostatic capacitance of cables being relatively high, it is necessary to arrange the surge generator with the maximum number of condenser units in parallel that is compatible with the output voltage required. The test voltage is applied between the two conductor terminals at the sealing ends, which are connected together, and the lead sheath which is solidly joined to the surge generator earth.

(*b*) *Switchgear*. Surge tests on switchgear are, in general, confined to gear rated at 11 kV and above.

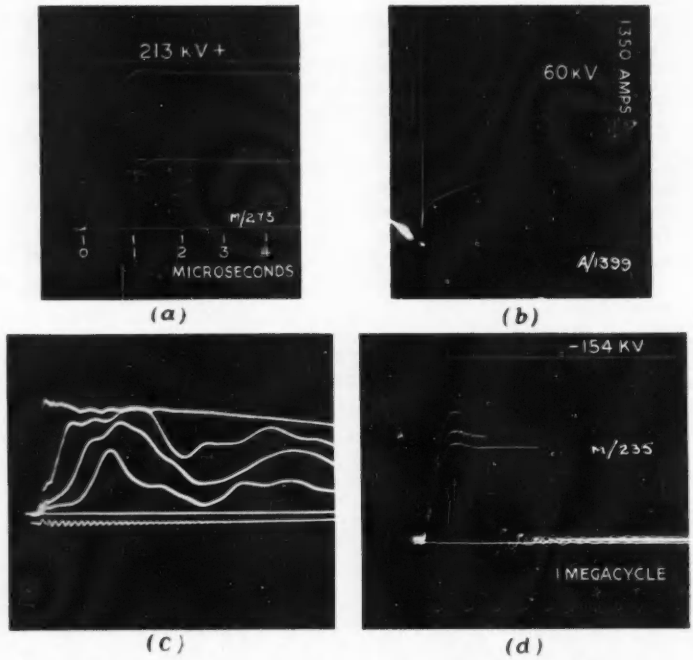

Fig. 10.—(*a*) Test voltage applied to 33 kV oil circuit breaker with and without a surge diverter. (*b*) Volt-ampere characteristic of 11 kV surge diverter. (*c*) Surge voltage distribution in 11 kV transformer winding. (*d*) Variation in time to flashover of 11 kV transformer protective gap with applied voltage.

The tests are usually made in three parts. First with the switch contacts closed the test voltage is applied between pairs of poles or phases ; second with the switch contacts closed between one pole or phase and earth ; third with the switch contacts open between the terminals of individual poles or phases. In every case three applications are made of either a positive or negative 1/50 microsecond wave having a peak value approximating to the formula 4·5 ($E+10$). Fig. 10 (*a*) shows an oscillogram of the test voltage of 200 kV (peak) applied to a 33 kV oil circuit breaker, and also the resulting modified surge obtained by connecting a 33 kV surge diverter across the breaker when it is again

subjected to the test voltage. The peak voltage has been limited to 145 kV (peak), by the protection afforded by the diverter.

(*c*) *Surge Diverters.* Type tests made on surge diverters are, necessarily, more varied and stringent than on other apparatus since the diverters are designed to protect other equipment from the full severity of an incoming surge. The ability of the diverter isolating spark gaps to operate with negligible time lag is determined by applying a surge having a 1/50 microsceond full waveshape and a peak value of $9E$ where E is the nominal service line voltage. The resulting modified surge, showing the operation of the diverter on the wavefront, is recorded oscillographically in the manner of fig. 10 (*a*). The impedance voltage drop across the diverter when discharging surge current is recorded as illustrated in fig. 10 (*b*). This is a volt-ampere characteristic for an 11 kV diverter passing a surge current of 1,500 amps. and demonstrates the non-linear relationship between the discharge current I and the impedance voltage drop V. This may be conveniently expressed in the approximate form $I=aV^b$. After the passage of surge current through the diverter, power frequency current will continue to flow. The diverter must limit and cut off this follow current and restore itself to its normal condition as soon as possible. Its ability to do so is determined by applying across the diverter a power frequency voltage 20 per cent in excess of its rated value, and causing the unit to operate a large number of times at one-minute intervals by the passage of surge current which initiates the flow of follow current. The interruption of this power frequency current must occur in the first half-cycle after the application of the surge in every case, and this is recorded oscillographically.

(*d*) *Transformers.* Surge tests on transformers present unique difficulties due to the complexity of the parameters of the windings, tapping sections and iron circuit.

The low-voltage recurrent-surge oscillograph is an invaluable tool for investigating the manner in which an applied surge varies with time throughout a winding. Its usefulness is enhanced by its portability, the speed at which photographic records may be taken, and the simplicity of selecting points for investigation on untanked transformers. Fig. 10 (*c*) is a representative oscillogram taken with this instrument on an 11 kV/400 volt transformer, and shows the applied wave and the volt-time characteristic at several points in the H.V. winding.

While the recurrent surge oscillograph may be used to give most valuable information about the distribution of surge voltage stresses in a transformer, it cannot be used to determine the ultimate surge strength of the windings.

In full-scale impulse testing, by reason of the relatively high self-capacitance and low impedance of large transformers, it is not possible to maintain a 1/50 microsecond waveshape and the wavefront time is usually nearer 2 microseconds. Since the maximum interturn stress is primarily a function of the rate of change $\frac{de}{dt}$ of the applied surge voltage, a chopped wave has to be employed. This is obtained by connecting in parallel with the winding under test a rod gap, which is set to flash over at the test voltage with a time lag of not less than 3 microseconds to ensure that the peak value of the surge has been attained. The sudden collapse of the voltage when the rod gap flashes over has the same effect on the interturn insulation as a corresponding steep-fronted wave. Two applications are made between the line terminal and earthed neutral. The rod gap is then removed and the test voltage reduced to the full wave value which is again calculated from the formula $4{\cdot}5\,(E+10)$. Two applications are made at this value which is designed to test the surge strength of the major insulation. For a 132 kV winding the full wave tests are made at 640 kV (peak) and the preceding chopped wave tests at a voltage 15 per cent greater : at 736 kV (peak).

(*e*) *Horn Gaps.* Fig. 10 (*d*) is an oscillogram of a series of volt-time characteristics for a protective horn gap fitted to an 11 kV transformer bushing. This shows the manner in which the time-lag-to-flashover varies inversely as the applied surge voltage. The many combinations of insulation, live electrodes and earthed metal used in high-voltage equipment all exhibit individual variations which influence this type of characteristic. These must be determined in order that the most economical and effective co-ordination of insulation and protective devices may be obtained.

A Modern Copper Rod Rolling Mill

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INTRODUCTION.

THE first essential in the manufacture of electric cable is, of course, the copper conductors. It is the purpose of this article to describe the copper rod rolling mill at the Pirelli-General Cable Works, Ltd., Eastleigh, in which wire bars, as received from the refineries, are rolled down to $\frac{1}{4}$ inch rod. Thereafter, in the Wire Drawing Department, the rod is further reduced to the many different gauges required for use in the production of every size and type of cable.

The plant, which is one of the most up-to-date of its kind, comprises a heating furnace, roughing train, finishing train and coilers, connected by suitable roller tables which successively convey the bars and partially rolled rod to the various sections of the mill. The entire installation is housed in a specially constructed building, a general view of which is seen in fig. 1, the production being arranged as a continuous process with the bars entering at one end and coming off the last conveyor as finished coils of $\frac{1}{4}$ inch rod. The mill is electrically driven throughout and, being largely automatic, is very economical of labour. The roughing train is electrically operated by one man from a central control platform, or pulpit, while on the finishing train three men are employed as " catchers ".

The output of the mill is sufficient to supply the whole of the G.E.C. Organisation as well as the requirements of a number of outside firms. As an indication of the degree of reduction obtainable, it is of interest to note that one bar can make about 3,000 miles of the finest gauge of wire.

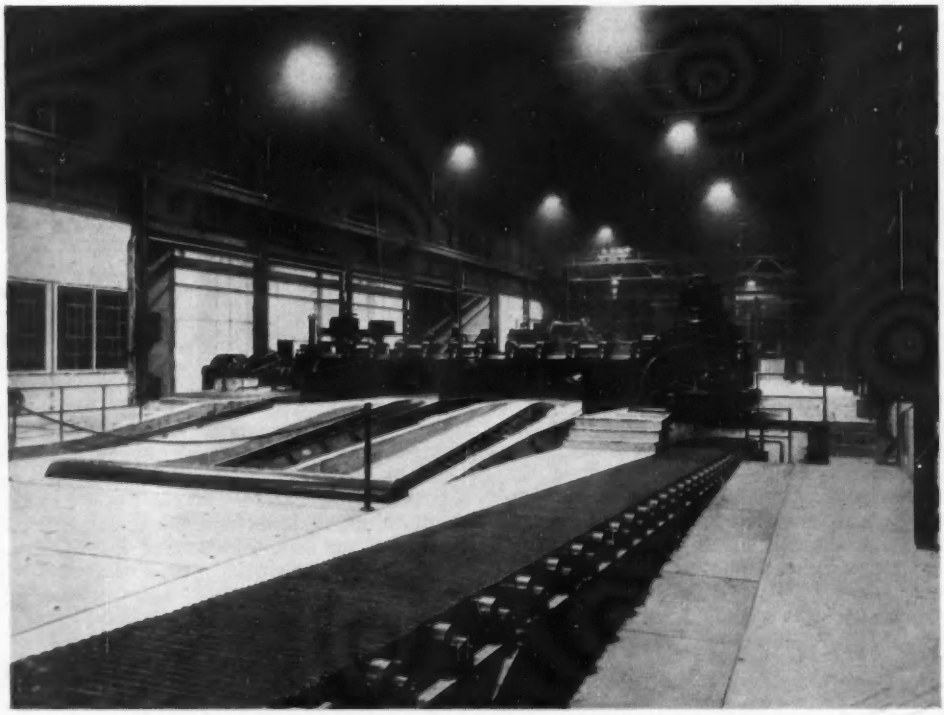

Fig. 1.—General view of the copper rod rolling mill.

Fig. 2.—The electrically operated ram charging the wire bars into the preheating furnace.

ROUGHING TRAIN.

The ingots, or wire bars as they are called, are of electrolytically refined copper of virtually 100 per cent purity. They are 54 ins. long and of rectangular section, approximately 4 ins. by 4⅜ ins., and weigh about 275 lbs.

A monorail crane picks up the bars from the stack in batches of eight and delivers them on to the furnace loading table. In due course they pass into the furnace, which holds 96 bars placed side by side, where they are heated to a temperature of about 900 degs. C. An electrically driven furnace pusher (fig. 2), operated from the central control platform, moves the whole charge forward sufficiently to tip the last bar on to the roller table at the delivery end. The live rollers carry the bar forward to the bar-turner which brings the set face into the proper position for the first pass (fig. 3). Thence the bar moves forward on to the tilting table which feeds it to the roughing train consisting of two 3-high stands (fig. 4). The first pass is between the middle and top rolls, whence the bar is ejected at the opposite side of the rolls on to a gravity manipulator which turns it through 90 degs. and allows it to fall on to a roller conveyor in line with the second pass which takes place between the middle and bottom rolls. A view of the roughing rolls from the manipulator side is seen in fig. 5. The bar again emerges on to the tilting table which has been lowered to line up with the outlet guide. The tilting table then raises the bar for the third pass which is again performed between the middle and top rolls, after which it is received by the second manipulator which turns it as before and sets it in line for the fourth pass between the middle and bottom rolls. Emerging once more on to the tilting table, which has been lowered to receive it, the bar is raised in line for the fifth pass between the middle and top rolls. It is then received by the third manipulator which once more turns it through 90 degs. and delivers it on to the live roller table for the sixth pass, which it leaves as rod of about 1¼ inches square section.

It will be readily understood that after the sixth pass the bar will have increased greatly in length, and it is impracticable to handle it any longer as a straight piece. From this point onwards it is therefore taken charge of by the repeaters which are looped channels which

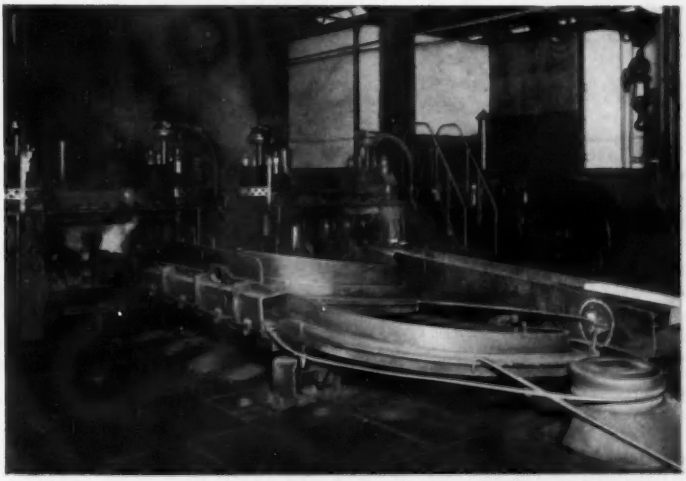

Fig. 3.—The approach side of the roughing train showing a bar on the approach rolls and partially rolled rod on one of the looping repeaters entering the box guide.

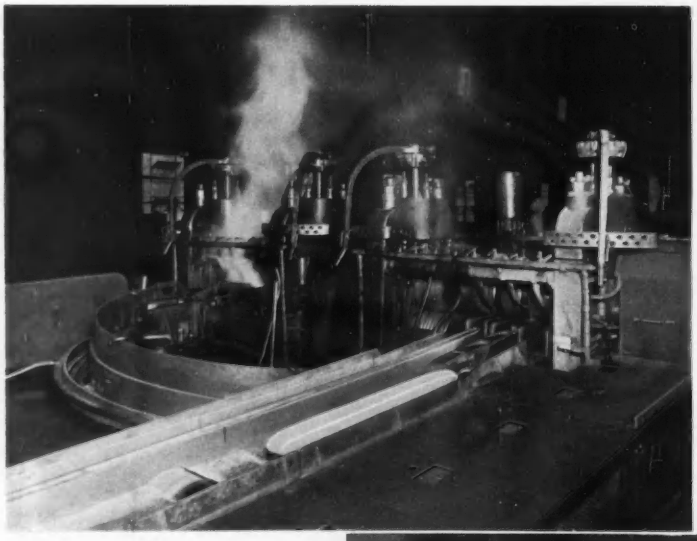

Fig. 4 (left).—A bar on the tilting table about to enter the first pass on the roughing mill.

Fig. 5 (below).—The roughing rolls from the manipulator side.

carry the foremost end of the bar completely round in a half-circle and feed it into the next pair of rolls. Sufficient space is allowed for the increasing length of bar to fall temporarily outside the channel into which it returns as the tail-end leaves the preceding rolls. As soon as the looping repeaters have taken charge, the process becomes automatic and is no longer under the control of the operator on the control platform. The seventh pass is made on the second stand and gives the rod an oval section; the eighth pass, between the middle and bottom rolls of the first stand, gives a square section; the ninth and final pass delivers the material as rod of about $1\frac{1}{8}$ inches by $\frac{5}{16}$ inch oval section.

As will be seen in the various illustrations, water jets are arranged to play on the bar at every pass. These serve the double purpose of breaking up the scale that forms on the surface of the copper and cooling the rolls and bearings. On the roughing train the bearings are of the synthetic resin type, water lubricated; on the finishing stands roller bearings are fitted.

FINISHING TRAIN.

On leaving the roughing train the rod goes directly to the finishing train which consists of seven 2-high stands (fig. 6). The use of an intermediate train is dispensed with as the last four reductions on the roughing train are essentially intermediate passes. This arrangement avoids the expense and complication of an additional stand with consequent economy of space and simplification of the rolling process.

As the rod leaves the last roughing stand it slides into a channel which turns it on edge and feeds it into the first pass of the finishing train. Coming out on the opposite side of the stand as a rod of square section (fig. 7), it is looped by a repeater to the first finishing oval pass, on leaving which it is seized by the catcher in a pair of tongs and fed manually to the third (square) pass. Thereafter it proceeds by normal square-oval progression to the seventh and final pass which it leaves as $\frac{1}{4}$ inch rod.

The handling of the rod on these stages is alternately manual and by repeaters. For the

square sections automatic repeating is employed, but for oval sections this is done manually as it is not easy to repeat rod of small oval section automatically without the possibility of occasional error.

There being nine passes on the roughing train and seven on the finishing train, the bar has now passed, in all, through sixteen reductions in the course of which its length has increased to rather more than a quarter of a mile. On the finishing train, channels are provided under the mill floor, as will be seen in fig. 6, to accommodate the increasing loops of rod at each stage as its cross-sectional area is reduced.

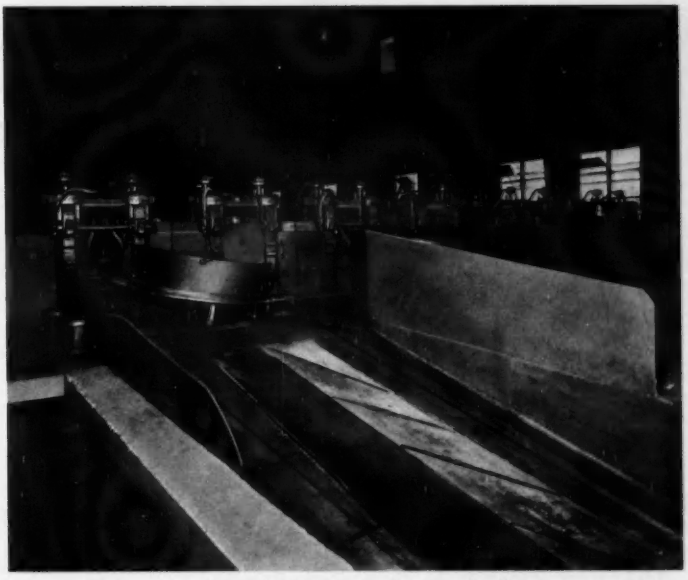

Fig. 7.—A rear view of the finishing train showing the first square repeater.

The finished rod passes to the coilers which wind the entire length into a single coil and drop it on to a conveyor which carries it to the delivery floor from where it is taken to the stack. Each of the two coilers is independently driven by a vertical spindle electric motor (fig. 8) ; the operations of coiling, stopping, releasing and re-starting are entirely automatic and under the control of time relays. It is most important that the speed of the coilers, should conform with any variations in rolling speed. To ensure this, the coiler motors are supplied from a generator driven by belting from the reduction gears. The voltage of this generator is proportional to its speed and thus the coilers accelerate or slow down in exact conformity with any fluctuations in rolling speed.

It should be noted that, when required, the mill can be arranged to produce round stock up to $\frac{3}{4}$ inch diameter, as well as a wide range of rectangular sections.

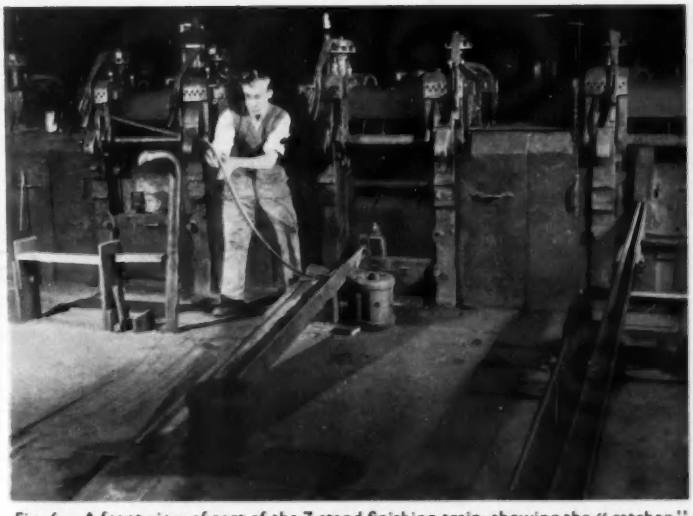

Fig. 6.—A front view of part of the 7-stand finishing train, showing the " catcher " looping the rod from the second to the third stand.

ELECTRICAL EQUIPMENT.

As already mentioned, the mill and its auxiliaries are electrically driven throughout. The supply is taken from the 6 kV, 3 phase mains and stepped down by a 1,200 kVA transformer to 440 volts for use in the mill. The incoming high tension side of the transformer is controlled

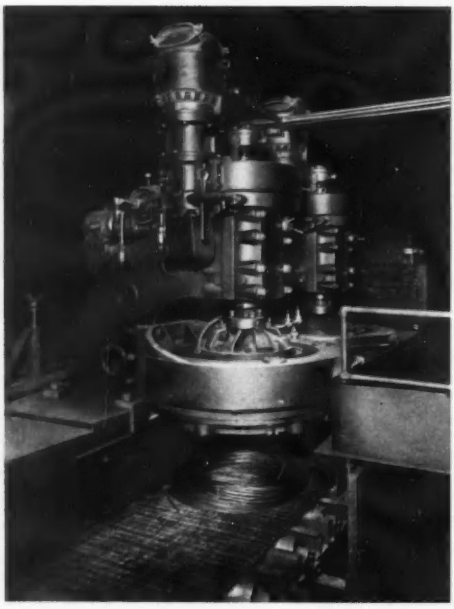

Fig. 8.—The two automatic coilers with a finished coil of ¼ inch rod on the conveyor.

from an S.V.D. board ; the outgoing supply is controlled by a 4-panel board comprising two 1,000 amp. pedestal type oil switches with two recording wattmeters, two reversing panels which serve to reverse the mill in case of jamming and two rotor resistance panels for speed adjustment.

The main drive of the roughing train is from a 400 h.p., 440 volt, 750 r.p.m. slipring induction motor which drives the rolls at 133 r.p.m. through reduction gearing (fig. 9). There are two flywheels mounted one at each side of the reduction gears. A similar arrangement embodying a 400 h.p. slipring motor, reduction gearing and one flywheel is used for the main drive of the finishing stands, but in this instance the speed of the rolls is 420 r.p.m.

For operating the crane which delivers the wire bars to the furnace three 440 volt, 1,000 r.p.m. D.C. motors are employed. These motors are rated at 30 h.p., 3 h.p. and 6 h.p., and drive, respectively, the crane hoist, lateral traverse on to the bridge and travel along the bridge. They are all hand controlled from the crane cabin.

The ram, or furnace pusher seen in fig. 2, is driven by a 15 h.p., 950 r.p.m. slipring motor through reduction gears fitted with a solenoid actuated brake. The motor has a contactor starter operated from the central control platform by means of a reversing controller, the crane and ram being electrically interlocked. The furnace rolls are driven by a 10 h.p., 950 r.p.m. slipring motor under push button contactor control from the platform. For the furnace fuel fan a star-delta started squirrel cage motor is fitted, rated at 8 h.p. and running at 2,870 r.p.m.

The bar-turner is actuated by a 1 h.p. squirrel cage motor and is push button started.

The live roll conveyor from the furnace and the tilting table feed rolls are driven by seventeen 2 h.p., 1,450 r.p.m. squirrel cage motors, the tilting table itself being operated through gearing by a 20 h.p., 712 r.p.m. slipring motor, contactor controlled from the central platform. The manipulator rolls on the delivery side of the roughing train employ six 2 h.p. squirrel cage motors. There are six lubricating oil pumps driven by 2 h.p., 1,400 r.p.m. squirrel cage machines with push button direct-to-line starters.

The water jets are supplied from a series of

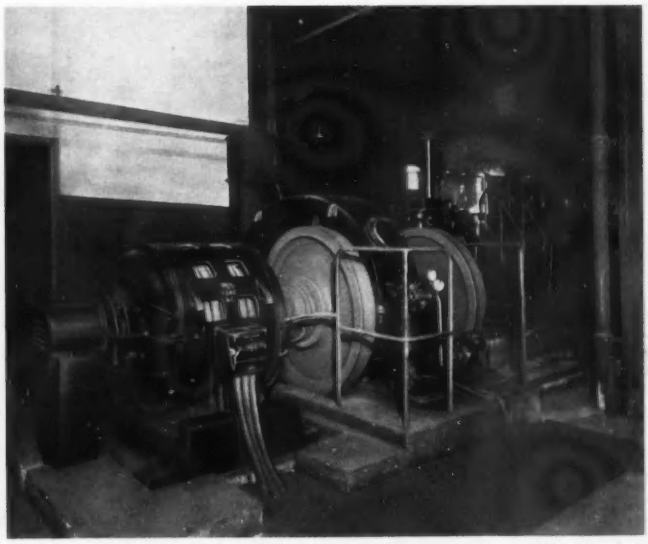

Fig. 9.—The main drive to the roughing train comprising a 400 h.p., 440 volt slipring induction motor with reduction gearing and two flywheels. The motor runs at 750 r.p.m. which is reduced to 133 r.p.m. for driving the rolls.

centrifugal pumps situated in the pump room and driven by three 10 h.p., 2,300/3,300 r.p.m. compound wound D.C. motors and one similar 4 h.p. motor. Contactor starting is employed for all machines. The water as it comes from the mill, runs into an underground conduit, the oil and other impurities being largely removed in a settling pool. It then passes to outside cooling ponds and is re-circulated by the pumps.

A lathe is provided for periodic machining of the rolls and this is driven through gearing from a 12 h.p., 440 volt, 300 r.p.m. D.C. motor controlled from a contactor panel.

Each of the automatic coilers is operated by a 7 h.p., 220 volt D.C. motor, the release mechanism being actuated by a similar motor rated at 1·5 h.p. The machines are all automatically contactor controlled.

The conveyor, seen in fig. 8, which transports the finished coils of $\frac{1}{4}$ inch rod to the delivery floor is driven through reduction gearing by an 8·5 h.p., 710 r.p.m. slipring induction motor controlled from a push button operated contactor panel.

Fig. 11.—The $\frac{1}{4}$ inch rod entering a 9-die continuous wire drawing machine where it is reduced to ·064 inch diameter.

It will be apparent that the operation of the mill is very largely automatic. The roughing train, however, is, for obvious reasons, under the general control of the operator on the pulpit who operates the furnace pusher, bar-turner, approach rolls, tilting table, tilting table conveyor and manipulator rolls.

Fig. 10.—A general view of the Wire Drawing Department.

WIRE DRAWING.

The coils of ¼ inch rod are prepared for drawing by first pickling them in an 8 to 12 per cent solution of sulphuric acid to remove the black oxide formed in the hot rolling process. The coils are then thoroughly washed with water at a pressure of 60 to 70 lbs. per sq. in. to remove all traces of acid and dipped in a fat solution to prevent re-oxidisation.

The drawing of the rod into wire for all normal purposes is a continuous process. A general view of this department is seen in fig. 10. The machines which deal with sizes between 0·196 ins. and 0·052 ins. from ¼ inch rod perform from three to nine operations, depending upon the finished sizes required. These machines are built on the tandem principle, that is, the hauling sheaves between each die are set in line. The final haul off is effected by a coiling block whence the wire passes to an automatic spooler if the finished material is required on spools. The machines are electrically driven at speeds from 800 to 2,200 ft. per min. according to the sizes of wire being manufactured, the slower speeds being used for the larger sizes. A 9-die machine which reduces ¼ inch rod down to 0·064 inch diameter is shown in fig. 11.

The reduction in cross-sectional area at each die ranges from 38 per cent in the first die to 10 or 11 per cent in the finishing die with a corresponding increase in length from 60 to 12 per cent. The machines handle all sizes of wire from 0·160 ins. to 0·052 ins.

Intermediate and fine wire drawing machines, each in their own group, deal with sizes down to the finest produced, which is ·0024 in. (46 S.W.G.) (fig. 12). On these types the hauling sheaves are arranged in sets of four to six in the form of a stepped pulley. The sheaves are of increasing diameter to accommodate the increased length of wire at each die. These types of machines operate at drawing speeds up to 5,000 ft. per minute.

It is important that the dies be properly lubricated and cooled and for this purpose a slurry made up of rape seed oil, soft soap and water in a highly emulsified state is used on all continuous drawing machines. On all groups of machines butt welding of coil to coil is employed to maintain continuous operation which eliminates re-threading of the dies at the end of each coil.

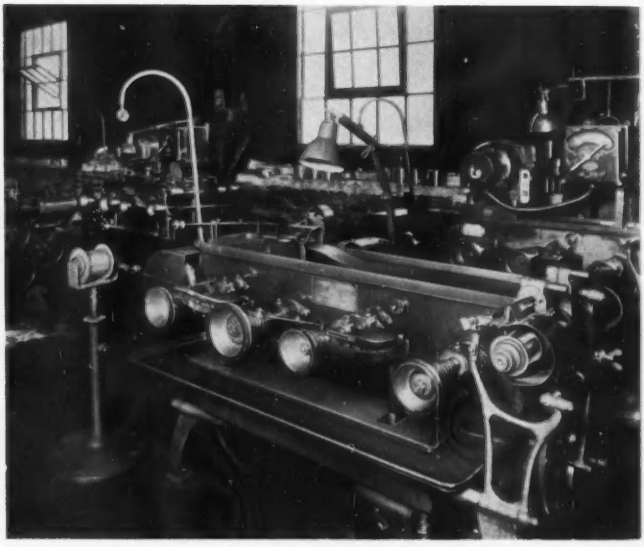

Fig. 12.—An 18-die continuous fine wire drawing machine in which the wire is drawn down to 46 S.W.G. The wire can be seen passing back and forth through the dies.

It should be appreciated that, under proper drawing conditions, reduction is brought about by the pull on the wire setting up a compressive stress between the metal and the die, causing the metal to flow.

As the bulk of the copper wire used for cable making is required in a ductile condition it is essential to anneal it after drawing. A bright annealing process is employed, after which the wire is tinned, if it is to be used for the manufacture of rubber insulated cable, to prevent its being attacked by rubber compounds during vulcanisation and, later, in service in the cable.

The subsequent processes involved in the manufacture of every type and size of wire and cable are beyond the scope of this article.

The Electrification of Tea Estates

By R. ALLAN, A.M.I.E.E.
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INTRODUCTION.

THE scheme of electrification which forms the subject of this article was carried out by the G.E.C. for the Bombay Burmah Trading Corporation Ltd. on their Mudis group of tea estates in the Annamalai Hills, South India.

The section of the Western Ghats known as the Annamalai Hills is about 80 miles from the coast of the Arabian Sea on the south-west of the Peninsula, the nearest point being Cochin, which up to the present has been inaccessible from the Annamalais. Access to the area is gained from the eastern side of the hills by way of a long and tortuous mountain road with very many sharp hairpin bends (fig. 2). The terrain is mountainous jungle subject to heavy rain and intense electrical storms.

Towards the end of the war it was found that the supply of firewood suitable for providing fuel for the producer gas engines was running dangerously low; it was decided, therefore, to change over to electric drive for the group comprising the factories Thai Mudi, Anai Mudi, Gajam Mudi and Mukottu Mudi and to use firewood only for air heating. A view of the Thai Mudi factory and part of the estate is seen in fig. 1.

TEA PRODUCTION.

Before considering the technical side of this scheme of electrification it is felt that a brief review of the whole process of tea making will prove of interest, beginning at the bush and ending in the domestic cup of tea.

Fig. 1.—Thai Mudi factory with the main outdoor substation. Some of the tea bushes are seen in the foreground.

Tea production is carried out, broadly, in the following steps : (*a*) picking, (*b*) withering, (*c*) rolling, (*d*) fermenting, (*e*) firing, (*f*) sifting and grading, (*g*) packing.

THE PLANT.

The tea plant is an evergreen bush which is kept carefully pruned to a height of about 2 to 3 ft. It flushes profusely during highly humid " greenhouse " conditions when the tea pickers are kept very busy picking off the green leaves and sending them to the factory. The average handling capacity of a factory in South India is about 8,000 lbs. of wet leaf in 24 hours.

Fig. 2.—The Annamalais Mountain Road.

WITHERING.

The wet leaf is passed into the factory and immediately spread out in a thin layer on " tats "—shelves of hessian fabric stretched between wires —and allowed to " wither " under the controlled flow of warm dry air (fig. 3). During this withering period the leaf loses about 40 per cent of its weight through moisture evaporation, and simultaneously a chemical action is taking place within the cell structure of the leaf. This change apparently demands several hours at about normal temperature, and rapid withering is therefore out of the question. If this withering action could be forced at high temperature to, say, one hour, the size of the factory could be cut down by 75 per cent.

ROLLING.

When the " wither " is complete the tea is taken to the Rolling Room which is kept cool and humid, put into rolling machines having brass or copper tables and rolled for about three hours. In this process the leaf is broken down, the leaf cells splitting to liberate essential oils and juices. Fermentation starts with the liberation of the mysterious enzymes or germs.

FERMENTATION.

The leaf, now very dark brown and moist, is stacked on the cool floor for about three hours to permit fermentation to continue to the required degree. When this point is reached, further fermentation must be arrested. This requires heat.

Fig. 3.—Part of the leaf withering loft.

FIRING.

The leaf is next taken to the Firing Room where it is dried at about 200 degs. F. to arrest fermentation and to drive off all remaining moisture.

The drying machine consists of a large metal case measuring about 15 ft. by 6 ft. by 6 ft. and containing a series of horizontal perforated metal racks of the endless belt type. The wet tea is fed in at the top, descends progressively from rack to rack, drying rapidly during its journey under the influence of a draught of hot air, heated from a wood- or oil-fired furnace. The tea finally emerges from the base of the drier, ready for the pot.

GRADING.

Although a certain amount of " roll breaking " and grading is done immediately after rolling, the tea is finally graded and cleaned before packing. The grades are known in the trade as (*a*) Broken Orange Pekoe, (*b*) Broken Pekoe, (*c*) Broken Pekoe Souchang, (*d*) Pekoe, (*e*) Orange Pekoe, (*f*) Fannings and (*g*) Dust.

ELECTRIFICATION SCHEME.

ELECTRICITY SUPPLY.

The main supply of electrical power is taken from the Pykara Hydro-Electric System of the Madras Government at 22 kV, 3 phase, 50 cycles, and is brought on an overhead line to a 6-pole terminal structure at the main substation at Thai Mudi which is the largest factory and situated at the geographical centre of the group (fig. 4). The consumption is metered at this point.

The main structure carries a 3-pole gang-operated airbreak switch with fuses, for controlling the incoming supply, and two 3-pole gang-operated airbreak switches with fuses, for the supply of Thai Mudi ; this supply is brought down to two 22 kV cable boxes mounted below. There are also three sets of 3-pole airbreak switches and fuses controlling the outgoing supply to the overhead line feeding the remaining three factories. In addition there is an interconnecting bus system and lightning arresters on all lines.

The transmission line is a 22 kV, 3-wire overhead line of 7/·064 hard-drawn bare copper carried on 35 ft. and 40 ft. poles, single poles carrying cross arms of the wishbone type. Owing to the very hilly nature of the ground, pole spacing is quite irregular, varying in span from 300 ft. to 1,300 ft. All poles are concreted and the majority of them are stayed.

It can be well understood that the transport of the poles, each weighing about 800 lbs., from railhead to site presented a difficult problem, as the hairpin bends on the road made it impossible to bring them up on lorries. The problem was solved by the Annamalais Ropeway Company who transported them up the mountain side by ropeway, each pole being supported on two carriers. The whole operation was carried out without mishap of any kind. A section of the ropeway at a road crossing is seen in fig. 5. The two baskets are each carrying a load of 800 lbs.

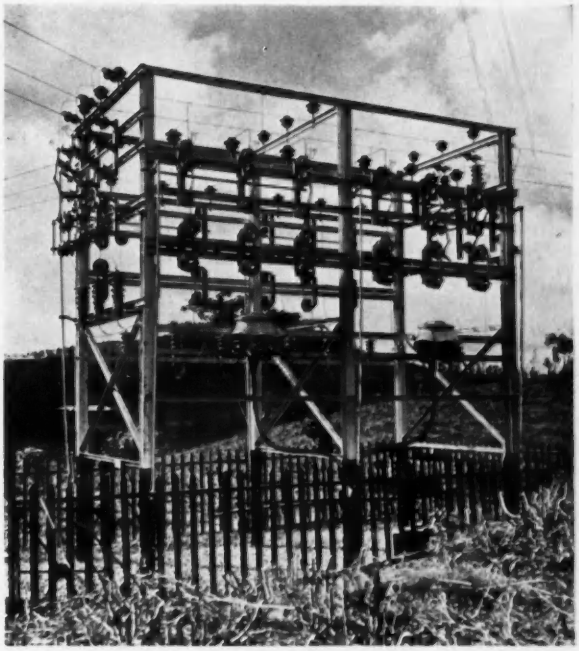

Fig. 4.—The 22 kV terminal structure at the main substation at Thai.

FACTORY ELECTRICAL EQUIPMENT.

The whole of the electrical gear for the various factories was supplied by the G.E.C. In general, the electrical equipment at each factory comprises :

(*a*) A 2-pole terminal structure at which the incoming 22 kV supply terminates and which also carries a 3 phase gang-operated airbreak switch and fuses, lightning arresters and H.T. cable box (fig. 6).

(*b*) A 100 kVA, 22 kV/400/230 volt transformer connected to the H.T. supply at the terminal structure through 22 kV paper insulated, lead covered, double steel tape armoured cable.

(*c*) A low tension oil switch controlling the incoming supply, with busbar chamber, oil switches for supply to the motors, and ironclad switch fuses for lighting and auxiliary circuits.

Fig. 6.—A 2-pole terminal structure taking the incoming 22 kV supply for one of the tea factories.

Special Precautions.

Owing to the severity of lightning storms in the area, a number of special precautions has to be taken. In all cases the 2-pole terminal supply structures are located at a distance of not less than 200 ft. from the factory. Where possible, all terminal structures are built with their tops below the crown of the hill on which the factory stands. The step-down transformers at each factory are of the indoor type and are connected to the H.T. supply through underground cables. The factories are all fitted with multiple lightning conductors numbering up to seven according to the roof area. All the overhead lines are equipped at both ends with lightning arresters.

Fig. 5.—A section of the ropeway transport system with two baskets in transit, each carrying a load of 800 lbs.

Machine Drives.

The following machines are generally involved in the operation of a tea factory: rollers, roll breakers, drying machines, cutters, sifters, withering fans and tea-dust extractor fans.

Rollers are usually run in banks of five or more from an engine-driven line shafting (fig. 7), but with the introduction of electricity in recent years the tendency has been to adopt individual drive for each roller. The power required is about 8 h.p., that is 40 h.p. for the bank of five rollers. However, the load on each roller fluctuates continuously between 25 per cent and 125 per cent of motor capacity so that, where justified by production conditions, group driving is to be preferred. With this arrangement the resultant overall load is

maintained reasonably level, smoother running is obtained due to the flywheel effect of pulleys and line shaft, and the installed horsepower can be reduced to about 30. On this account the use of individual geared-motor units is open to criticism.

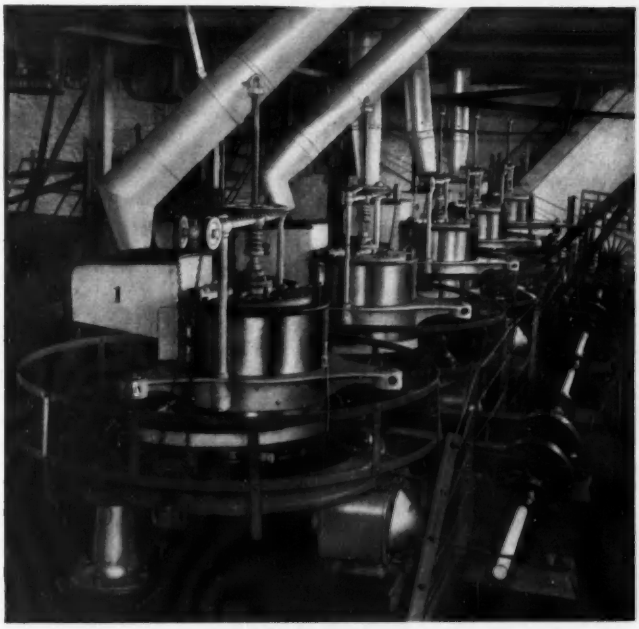

Fig. 7.—A bank of five tea rollers.

Roll breakers of the horizontal vibrating type usually require a drive of about 2 h.p. The drying machine takes about 7 h.p. and electric heating is not popular nor does it appear justifiable unless electric energy is available at extremely low rates. Night firing, using electric heaters on a low tariff, may eventually be adopted, but it is likely to be some time before such a change is made.

Withering fans are generally run in pairs, the fans being between 72 ins. and 96 ins. in diameter and running at about 120 r.p.m. Each pair requires about 7 h.p. The fans are used for circulating hot air from the firing furnace through the withering lofts.

The remainder of the machinery consists of sundry small machines such as cutters, sifters, packer and exhaust fans, totalling, in all, some 5 to 7 h.p.

LAYOUT OF DRIVES.

Owing to wartime difficulties in obtaining plant and machinery it was decided to adopt group drives using all the existing shafting, but instead of replacing the gas engine by a single motor, the shafting was split at convenient points and two or more motors installed. In all factories the main shaft is split at the centre of the building, which is also approximately the centre of the load, and the ends of the shaft are fitted with chain-operated claw clutches. Two motors of suitable power are installed at this point and connected to their respective shafts through "Texrope" drives as seen in fig. 8 which illustrates the main drive at Anai Mudi.

With the factory on full load, each motor drives its own section of line shafting. During certain periods of low load when the total load is within the capacity of one motor, the other motor is shut down, the clutches engaged and one machine drives the whole line shaft. Load conditions can be so arranged that the total load is never less than half the total motor capacity. The arrangement has the further advantage that, in the event of one motor's breaking down, the factory can continue running on half output until repairs have been made or a replacement motor fitted.

Wherever possible all the drives throughout

the group are arranged so that the lengths of all "V" ropes are the same, thus simplifying the stocking of spares. The motors were standardised at 30 h.p. and 60 h.p. and one spare motor of each rating is held in reserve.

LIGHTING.

In the rolling and drying rooms 5 ft. Osram fluorescent lamps in industrial type reflectors give very satisfactory illumination. The lighting of the withering loft is by means of bulkhead fittings in the roofs of the passage-ways. Gripper type hand lamps fitted with 12 inch diameter dispersive reflectors and lamp guards are used for close inspection of leaf racks. The hand lamps are arranged to clip on vertical poles beside the racks and can be moved to illuminate individual shelves as may be required. The tough rubber sheathed flexible leads are hung on cradles to ensure that they are always kept clear of the floor and do not cause obstruction in the passages.

CONCLUSION.

The changeover to electric drive in the tea factories has resulted in a considerable saving of space within the buildings : directly by eliminating the engine house, and indirectly by doing away with the necessity of storing large quantities of firewood. It has also put an end to the stripping of forests and has relieved the burden on the already harassed transport system.

The introduction of electric power has undoubtedly brought many benefits in its train. In the tea factories of the future one may look forward to the use of group drives on rollers with individual electric drive for the remainder of the plant ; electric heating and drying a

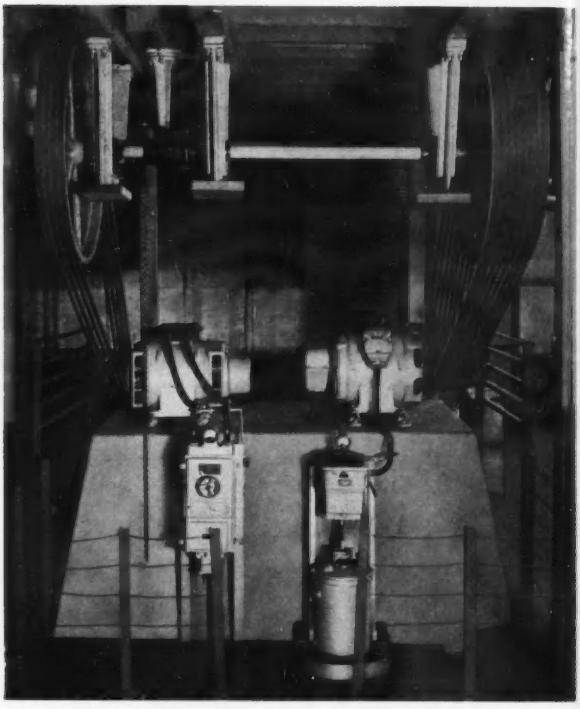

Fig. 8.—Anai Mudi tea factory : the main drives to the line shafting.

special low tariff rates for night loads and, possibly, the use of ultra-violet light to control fermentation and to sterilise roller trays.